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**Artificial Intelligence,
Digital Transformation and
Contemporary Challenges /
*Inteligencia Artificial, Transformación
Digital y desafíos contemporáneos***

Octaedro  **Editorial**
Barcelona, 2026



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EDICIÓ / EDITED BY: Urtza Garay, Christos Lalos (Eds.)

Revisión y maquetación: Esperança Martínez

Primera edición: junio 2026

© De la edición: Urtza Garay y Christos Lalos

© Del texto: Las autoras y autores

© De esta edición:

Ediciones OCTAEDRO, S.L.

C/ Bailén, 5 – 08010 Barcelona

Tel.: 93 246 40 02 – Fax: 93 231 18 68

www.octaedro.com – octaedro@octaedro.com

ISBN: 978-84-1079-419-1

Producción: Ediciones Octaedro

La revisión de los trabajos se ha realizado de forma rigurosa, siguiendo el protocolo de revisión por pares.

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Publicación en *Open Access* – Acceso abierto

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Introduction / Introducción

Artificial Intelligence, Digital Transformation and Contemporary Challenges: Educational, Ethical and Human Perspectives

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Christos Lalos

(Athens)

Artificial intelligence (AI) and digital transformation have become defining forces in contemporary society, influencing education, healthcare, governance, and human development. This volume presents an interdisciplinary exploration of these phenomena through a collection of studies that address the opportunities, risks, and ethical considerations associated with technological innovation. Divided into three thematic sections, the work considers the impact of AI on educational systems, the relationship between technology and health, and broader historical and philosophical perspectives that contextualise current digital developments.

1st Section: Artificial Intelligence and Digital Transformation in Education

The first section of the volume focuses primarily on the transformation of education through digital technologies and artificial intelligence. A central theme throughout these chapters is the increasing integration of algorithmic systems into educational environments and the consequent need for effective governance and ethical oversight.

Liovas analyses the algorithmic transformation of the Greek educational system between 2020 and 2025, highlighting the growing influence of AI-driven policies and data-based decision-making processes. The chapter demonstrates how educational institutions increasingly rely on digital tools to improve administrative efficiency and support teaching practices. However, it also raises concerns regarding transparency, accountability, and the ethical implications of algorithmic governance. These issues are particularly significant because educational decisions directly affect learners' opportunities and outcomes.

Similarly, Skaras addresses the broader process of digital transformation within higher education. Universities are increasingly adopting emerging technologies, including learning analytics, intelligent tutoring systems, and AI-assisted administrative platforms. While these innovations offer opportunities for personalisation and institutional efficiency, they also introduce challenges related to data protection, algorithmic bias, and institutional responsibility. The chapter argues that technological innovation must be accompanied by clear governance frameworks capable of ensuring ethical and equitable implementation.

Another important contribution is Vlami's critical literature review on barriers to teachers' AI literacy. The study identifies several obstacles that prevent educators from effectively engaging with AI technologies, including insufficient training, limited technical expertise, and uncertainty regarding the pedagogical value of AI applications. The findings emphasise that successful digital transfor-

mation depends not only on technological infrastructure but also on the professional development of teachers. Without adequate preparation, educators may struggle to integrate AI meaningfully into their teaching practices.

The importance of digital literacy is further explored by Papagiannis, who examines the role of school initiatives in developing students' digital competencies. The chapter argues that digital literacy should be understood as a multidimensional concept encompassing technical skills, critical thinking, information evaluation, and responsible digital citizenship. Educational institutions therefore have a crucial role in preparing students to participate effectively in increasingly digital societies.

Complementing this perspective, Tsapardoni examines the contribution of digital technology to education more broadly. The chapter highlights the benefits of digital tools for communication, collaboration, and access to educational resources. At the same time, it acknowledges the existence of digital inequalities that may limit access to these opportunities. Consequently, the effective use of educational technology requires strategies that address issues of inclusion and accessibility.

Additional chapters broaden the discussion by examining innovative pedagogical approaches. Amar, Amar, and Amar explore co-teaching as a model that enables the coexistence of face-to-face and virtual learning environments. This approach reflects the growing demand for flexible educational models capable of adapting to diverse learning contexts. Meanwhile, Martinez-Roig analyses future teachers' perceptions of social robotics in educational contexts, providing deep insight into attitudes towards emerging forms of human-machine interaction within learning environments.

The educational section concludes with Tsapardoni's discussion of the crisis in education during the COVID-19 pandemic. The pandemic accelerated digital transformation worldwide, forcing institutions to adopt remote learning solutions rapidly. This experience exposed both the potential of digital technologies and the limitations of existing educational systems, particularly regarding technological readiness and equal access to learning opportunities.

2nd Section: Health, Ethics and Human Development

The second major theme of the volume concerns the relationship between technology, health, and ethics. Katogianni explores the opportunities and challenges associated with the increasing use of AI within healthcare systems. AI technologies are becoming important tools in diagnostics, patient monitoring, medical research, and treatment planning. These applications have the potential to improve healthcare outcomes through greater efficiency, accuracy, and predictive capacity. Nevertheless, the chapter emphasises that technological progress must be balanced by ethical considerations. Questions concerning patient privacy, informed consent, accountability, and algorithmic fairness remain significant concerns. Healthcare decisions involve complex human factors that cannot be fully reduced to computational processes.

Katogianni argues that AI should complement rather than replace human medical expertise. While algorithms can process large quantities of data and identify patterns that may be difficult for humans to detect, healthcare also requires empathy, professional judgement, and ethical reasoning. Consequently, the chapter advocates a human-centred approach to AI implementation in medicine. The discussion of human wellbeing is further developed by Kouvara's chapter on the Mediterranean diet and gut microbiota. Although not directly related to artificial intelligence, this contribution reinforces the volume's broader interest in health and human development. The study highlights the relationship between nutrition and microbiological health, demonstrating the importance of interdisciplinary approaches to understanding wellbeing. Its inclusion reminds readers that technological innovation represents only one dimension of human progress.

3rd Section: Historical and Philosophical Perspectives

The final section provides a broader intellectual framework for understanding contemporary technological developments. Castillo Ochoa examines the evolution of concepts of symmetry from ancient notions of commensurability through medieval proportional thinking to modern theories of invariance. This historical perspective demonstrates that scientific and technological knowledge develops through long-term intellectual processes rather than sudden transformations. The chapter encourages readers to situate contemporary digital innovations within wider traditions of philosophical and mathematical thought. Such an approach is particularly relevant in discussions of artificial intelligence, where questions concerning knowledge, rationality, and representation have deep historical roots. By connecting contemporary technological debates with broader intellectual traditions, the chapter enriches the volume's interdisciplinary character and highlights the value of historical reflection when analysing present-day innovations.

Conclusion

In essence, to conclude, the volume offers a comprehensive examination of the opportunities and difficulties associated with technological change in the twenty-first century. Across its various contributions, several interconnected themes emerge, including the transformation of educational systems, the ethical implications of AI in healthcare, the importance of digital literacy, and the need to contextualise technological innovation within broader historical and philosophical frameworks. A consistent message throughout the collection is that technological progress must be accompanied by ethical responsibility and effective governance. Artificial intelligence and digital technologies possess considerable potential to improve education, healthcare, and social development, yet their successful implementation depends on maintaining human-centred values and addressing issues of equity, transparency, and accountability.

Overall, the volume provides a valuable interdisciplinary contribution to contemporary debates on digital transformation, demonstrating that the future of technology cannot be separated from the social, ethical, and cultural contexts in which it is developed and applied.

INTRODUCCIÓN

Inteligencia Artificial, Transformación Digital y Desafíos Contemporáneos: Perspectivas Educativas, Éticas y Humanas

Urtza Garay

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(Athens)

La inteligencia artificial (IA) y la transformación digital se han convertido en fuerzas determinantes de la sociedad contemporánea, influyendo en la educación, la atención sanitaria, la gobernanza y el desarrollo humano. El presente libro ofrece una exploración interdisciplinar de estos fenómenos mediante una colección de estudios que abordan las oportunidades, los riesgos y las consideraciones

éticas asociadas a la innovación tecnológica. Dividida en tres secciones temáticas, el libro examina el impacto de la IA en los sistemas educativos, la relación entre tecnología y salud, y perspectivas históricas y filosóficas más amplias que contextualizan los desarrollos digitales actuales.

1ª sección: Inteligencia Artificial y Transformación Digital en la Educación

La primera sección del volumen se centra principalmente en la transformación de la educación a través de las tecnologías digitales y la inteligencia artificial. Un tema central a lo largo de estos capítulos es la creciente integración de sistemas algorítmicos en los entornos educativos y la consiguiente necesidad de una gobernanza eficaz y una adecuada supervisión ética.

Liovas analiza la transformación algorítmica del sistema educativo griego entre 2020 y 2025, destacando la creciente influencia de las políticas impulsadas por la IA y de los procesos de toma de decisiones basados en datos. El capítulo demuestra cómo las instituciones educativas recurren cada vez más a herramientas digitales para mejorar la eficiencia administrativa y apoyar las prácticas docentes. Sin embargo, también plantea preocupaciones relacionadas con la transparencia, la rendición de cuentas y las implicaciones éticas de la gobernanza algorítmica. Estas cuestiones son especialmente relevantes porque las decisiones educativas afectan directamente a las oportunidades y resultados del alumnado.

De manera similar, Skaras aborda el proceso más amplio de transformación digital en la educación superior. Las universidades están adoptando progresivamente tecnologías emergentes, entre ellas la analítica del aprendizaje, los sistemas inteligentes de tutoría y las plataformas administrativas asistidas por inteligencia artificial. Aunque estas innovaciones ofrecen oportunidades para la personalización y la eficiencia institucional, también introducen desafíos relacionados con la protección de datos, los sesgos algorítmicos y la responsabilidad institucional. El capítulo sostiene que la innovación tecnológica debe ir acompañada de marcos de gobernanza claros que garanticen una implementación ética y equitativa.

Otra contribución destacada es la revisión crítica de la literatura realizada por Vlami sobre las barreras para la alfabetización en inteligencia artificial del profesorado. El estudio identifica diversos obstáculos que dificultan la participación efectiva de los docentes en el uso de tecnologías de IA, entre ellos una formación insuficiente, una experiencia técnica limitada y la incertidumbre respecto al valor pedagógico de las aplicaciones basadas en IA. Los resultados subrayan que una transformación digital exitosa depende no solo de la infraestructura tecnológica, sino también del desarrollo profesional del profesorado. Sin una preparación adecuada, los docentes pueden encontrar dificultades para integrar la inteligencia artificial de manera significativa en sus prácticas educativas.

La importancia de la alfabetización digital es analizada además por Papagiannis, quien examina el papel de las iniciativas escolares en el desarrollo de las competencias digitales del alumnado. El capítulo sostiene que la alfabetización digital debe entenderse como un concepto multidimensional que incluye habilidades técnicas, pensamiento crítico, evaluación de la información y ciudadanía digital responsable. Por tanto, las instituciones educativas desempeñan un papel fundamental en la preparación de los estudiantes para participar eficazmente en sociedades cada vez más digitalizadas.

Complementando esta perspectiva, Tsapardoni examina la contribución de la tecnología digital a la educación de manera más amplia. El capítulo destaca los beneficios de las herramientas digitales para la comunicación, la colaboración y el acceso a recursos educativos. Al mismo tiempo, reconoce la existencia de desigualdades digitales que pueden limitar el acceso a estas oportunidades. En consecuencia, el uso eficaz de la tecnología educativa requiere estrategias que aborden cuestiones de inclusión y accesibilidad.

Otros capítulos amplían de modo decisivo el debate mediante el análisis de enfoques pedagógicos innovadores. Amar, Amar y Amar exploran la codocencia como un modelo que permite la coexistencia de entornos de aprendizaje presenciales y virtuales. Este enfoque refleja la creciente demanda de modelos educativos flexibles capaces de adaptarse a diversos contextos de aprendizaje. Por su parte, Martínez-Roig analiza las percepciones de los futuros docentes sobre la robótica social en contextos educativos, proporcionando una comprensión profunda de las actitudes hacia las nuevas formas de interacción entre seres humanos y máquinas en los entornos de aprendizaje.

La sección educativa concluye con la reflexión de Tsapardoni sobre la crisis educativa durante la pandemia de COVID-19. La pandemia aceleró la transformación digital a escala mundial, obligando a las instituciones a adoptar rápidamente soluciones de aprendizaje a distancia. Esta experiencia puso de manifiesto tanto el potencial de las tecnologías digitales como las limitaciones de los sistemas educativos existentes, especialmente en lo que respecta a la preparación tecnológica y a la igualdad de acceso a las oportunidades de aprendizaje.

2ª sección: Salud, Ética y Desarrollo Humano

El segundo gran tema del volumen se refiere a la relación entre tecnología, salud y ética. Katogianni explora las oportunidades y los desafíos asociados al creciente uso de la inteligencia artificial en los sistemas sanitarios. Las tecnologías de IA se están convirtiendo en herramientas fundamentales para el diagnóstico, la monitorización de pacientes, la investigación médica y la planificación de tratamientos. Estas aplicaciones tienen el potencial de mejorar los resultados sanitarios mediante una mayor eficiencia, precisión y capacidad predictiva. No obstante, el capítulo subraya que el progreso tecnológico debe equilibrarse con consideraciones éticas. Las cuestiones relacionadas con la privacidad de los pacientes, el consentimiento informado, la responsabilidad y la equidad algorítmica continúan siendo preocupaciones significativas. Las decisiones sanitarias implican factores humanos complejos que no pueden reducirse completamente a procesos computacionales.

Katogianni sostiene que la inteligencia artificial debe complementar, y no sustituir, la experiencia médica humana. Aunque los algoritmos pueden procesar grandes cantidades de datos e identificar patrones difíciles de detectar para las personas, la atención sanitaria también requiere empatía, juicio profesional y razonamiento ético. En consecuencia, el capítulo defiende un enfoque centrado en la persona para la implementación de la IA en el ámbito médico.

La discusión sobre el bienestar humano se desarrolla además en el capítulo de Kouvara dedicado a la dieta mediterránea y la microbiota intestinal. Aunque esta contribución no está directamente relacionada con la inteligencia artificial, refuerza el interés general del volumen por la salud y el desarrollo humano. El estudio destaca la relación entre la nutrición y la salud microbiana, demostrando la importancia de los enfoques interdisciplinarios para comprender el bienestar. Su inclusión recuerda a los lectores que la innovación tecnológica representa únicamente una de las múltiples dimensiones del progreso humano.

3ª sección: Perspectivas Históricas y Filosóficas

La sección final proporciona un marco intelectual más amplio para comprender los desarrollos tecnológicos contemporáneos. Castillo Ochoa examina la evolución de los conceptos de simetría desde las nociones antiguas de conmensurabilidad, pasando por el pensamiento proporcional medieval, hasta las teorías modernas de la invariancia. Esta perspectiva histórica demuestra que el conocimiento científico y tecnológico se desarrolla mediante procesos intelectuales de larga duración y no a través de transformaciones repentinas. El capítulo anima a los lectores a situar las innovaciones digitales contemporáneas dentro de tradiciones más amplias del pensamiento filosófico y matemático. Este

enfoque resulta especialmente relevante en los debates sobre inteligencia artificial, donde cuestiones relacionadas con el conocimiento, la racionalidad y la representación poseen profundas raíces históricas. Al conectar los debates tecnológicos contemporáneos con tradiciones intelectuales más amplias, el capítulo enriquece el carácter interdisciplinar del volumen y pone de relieve el valor de la reflexión histórica para analizar las innovaciones actuales.

En definitiva, para concluir, este libro ofrece un examen exhaustivo de las oportunidades y dificultades asociadas al cambio tecnológico en el siglo XXI. A través de sus diversas contribuciones emergen varios temas interrelacionados, entre ellos la transformación de los sistemas educativos, las implicaciones éticas de la inteligencia artificial en la atención sanitaria, la importancia de la alfabetización digital y la necesidad de contextualizar la innovación tecnológica dentro de marcos históricos y filosóficos más amplios. Un mensaje constante a lo largo de toda la obra es que el progreso tecnológico debe ir acompañado de responsabilidad ética y de mecanismos eficaces de gobernanza. La inteligencia artificial y las tecnologías digitales poseen un considerable potencial para mejorar la educación, la atención sanitaria y el desarrollo social; sin embargo, su implementación exitosa depende del mantenimiento de valores centrados en las personas y de la atención a cuestiones de equidad, transparencia y rendición de cuentas.

En conjunto, el volumen constituye una valiosa contribución interdisciplinar a los debates contemporáneos sobre la transformación digital, demostrando que el futuro de la tecnología no puede separarse de los contextos sociales, éticos y culturales en los que se desarrolla y aplica.

Part I
**Artificial Intelligence and Digital
Transformation**

1. Artificial intelligence and human health. Ethical and medical boundaries

Katogianni Kleio

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Abstract: Artificial Intelligence (AI) has rapidly transformed the healthcare sector, reshaping diagnostic practices, therapeutic decision-making, and interactions among medical professionals, patients, and technology. Through machine learning and deep learning techniques, AI systems increasingly support clinical decision-making, disease prediction, personalized treatment, and the optimization of health services. While these technologies promise improved accuracy, efficiency, and reduced human error, their integration into medical practice also raises complex ethical, social, and professional challenges (Topol, 2019). This paper provides a theoretical and critical analysis of the role of Artificial Intelligence in modern healthcare, focusing on the ethical issues and medical limitations that appear from its use. It examines how AI applications, from radiological image analysis to chronic disease prognosis, are changing the clinical practice and healthcare research while at the same time introducing risks related to responsibility, transparency, data privacy, bias, and the potential depersonalization of care. Some central questions addressed at this paper include accountability for algorithmic errors, the limits of automated medical decision, and also the preservation of human presence in medical decision-making. This essay argues that AI should be understood neither as a threat nor as a universal solution, but as a tool for the human empowerment, by emphasizing the need for a human-centered ethical framework grounded in fairness, responsibility, beneficence, and respect for human dignity, developed through interdisciplinary collaboration among healthcare professionals, engineers, legal scholars, and ethicists.

Keywords: artificial intelligence, AI, prognosis, framework, ethical, boundaries, health, ehealth, telemedicine, legal

1. INTRODUCTION

The electronic health and her tools stand at the forefront of a transformative period in health sector, where the technology and the data converge to change the way we understand and deliver healthcare. With unprecedented volumes of information drawn from individuals' lifestyles, medical histories, and biological traits, this field is redefining what is possible in patient care and public health. According to the American Food and Drug Administration (2017), the e-health includes a wide collection of innovations, including m-Health, health IT, mobile devices, telemedicine, and personalized medicine. As stated by Groves et al. (2013) these progress rely on a dynamic health data ecosystem that integrates information from electronic health records, diagnostic tools, and beyond. But also ehealth is characterized by its volume, complexity, and diversity, this wealth of information, often referred to as big biomedical data and requires sophisticated analysis and data mining techniques to unlock its full potential (Vayena & Blasimme, 2017). Remarkably, the literacy about the digital health is on the rise, mainly among younger and more educated populations who increasingly turn to online resources for information about health (Tennant et al., 2015). This paper introduces us the rapid evolution of digital health, setting the stage for an in-depth exploration of its benefits, challenges, but also the ethical boundaries of it.

Although there is literature on the subject and the world has modernized, there is still skepticism surrounding artificial intelligence, especially in the healthcare sector, which is closely linked to more traditional practices. People are not fully aware of how many fields artificial intelligence is already being used in and to what extent it is legally protected.

Artificial Intelligence (AI) has emerged as one of the most dynamic and transformative fields of computer science, referring to the development of computational systems capable of performing tasks that traditionally need human intelligence, such as learning, reasoning, perception, and making decisions. Since its theoretical origins in the mid-twentieth century, AI has evolved from theoretical experimentation into a potent technological force with profound implications across multiple domains, particularly in healthcare (Russell & Norvig, 2021; Topol, 2019).

In recent years, advances in machine learning (ML) and deep learning have significantly expanded the capabilities of AI-driven systems, enabling their integration into clinical decision-making, medical diagnostics, disease prognosis, and personalized treatment planning. These technologies rely on large-scale data collection, algorithmic model construction, and continuous evaluation and validation, enabling systems to improve performance over time. In healthcare settings, such systems promise increased diagnostic accuracy, greater efficiency, and reduced human error, contributing to improved health outcomes and optimized medical services (Esteva et al., 2017; Topol, 2019).

Despite these benefits, the growing presence of AI in the health sector has generated intense ethical, social, and professional debate. Concerns about responsibility, transparency, data privacy, algorithmic bias, and the potential erosion of human-centered care challenge traditional understandings of medical practice. The increasing influence of AI systems on medical decisions raises critical questions regarding the limits of automation, the role of healthcare professionals, and the preservation of trust between patients and health professionals.

This paper adopts a theoretical and critical perspective to examine the ethical concerns and medical boundaries associated with the use of Artificial Intelligence in healthcare. By exploring both the technological foundations and the moral implications of AI-driven medical systems, the chapter aims to contribute to an interdisciplinary dialogue that emphasizes the need for a human-centered ethical framework, ensuring that technological innovation serves human health and dignity rather than undermining them.

2. BACKGROUND

In Healthcare, Machine Learning (ML) is a core subfield of AI that focuses on developing algorithms and computational models that learn from data to perform specific tasks. Unlike the traditional systems, the machine learning models can develop their performance through exposure to data and adapt to new information and evolving conditions. This adaptive capacity has enabled a wide range of innovative applications, including medical image recognition, predictive analytics, clinical decision support, and disease diagnosis. As we can understand, the machine learning approaches can be categorized into supervised, unsupervised, and reinforcement learning, depending on the nature of the data and the learning objective. The supervised learning relies on labeled datasets to establish relationships between inputs and known outcomes, making it particularly suitable for diagnostic and prognostic tasks in healthcare. On the other hand, the unsupervised learning aims to identify hidden patterns or structures within unlabeled data, contributing to patient stratification and population health analysis. Reinforcement learning focuses on sequential decision-making, enabling systems to optimize actions based on feedback from their environment, with emerging applications in treatment planning and resource allocation.

The principal characteristic of e-health lies not in technology itself, but in the centrality of data. The aim of digital health can be conceptualized as establishing a dynamic flow of information: beginning with patient-generated data, progressing to devices and/or healthcare professionals for analysis and utilization, and ultimately returning to devices that furnish patients with actionable insights regarding their health status and management strategies (Eisensten, 2012).

To this end, various types of information about the patient's health must be collected, as well as data on the patient's socioeconomic status, living environment, and broader context. Information posted on social media may also be relevant to both individual and population health (Flahault et al., 2017).

Through these learning paradigms, machine learning provides powerful tools for analyzing large-scale, complex medical data, supporting healthcare professionals in managing uncertainty, enhancing diagnostic accuracy, and improving clinical outcomes.

3. MAIN FOCUS OF THE CHAPTER

3.1 Applications of AI in Modern Medical Practice

Medical imaging constitutes one of the most critical support of modern clinical practice, enabling the detection, diagnosis, and monitoring of a wide range of diseases. Technologies such as X-rays, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and positron emission tomography (PET) provide clinicians with detailed visual representations of internal anatomical and functional processes, supporting informed clinical decision-making, treatment planning, and prognosis assessment. In contemporary healthcare, medical imaging is closely linked to the principles of personalized medicine, as it allows diagnostic and therapeutic approaches to be tailored to the specific characteristics of individual patients.

In recent years, the integration of Artificial Intelligence, particularly machine learning and deep learning, has significantly transformed the field of medical imaging. AI-based systems are increasingly used to analyze complex imaging data, detect subtle patterns, and assist in identifying abnormalities that may be difficult to recognize through human observation alone. The applications shows the evolution on health sector, including tumor detection in MRI and CT scans, automated classification of radiological findings, image segmentation, and the prioritization of critical cases in clinical workflows. These systems promise improved diagnostic accuracy, reduced interpretation time, and support for radiologists in managing growing imaging workloads.

Despite these advantages, the use of AI in medical imaging raises significant ethical and professional concerns. The reliance on algorithmic interpretation introduces questions regarding accountability in cases of misdiagnosis, transparency of decision-making processes, and the potential overreliance on automated systems. Furthermore, biases embedded in training datasets may affect diagnostic performance across different populations, potentially reinforcing existing inequalities in healthcare access and outcomes. As a result, AI systems in medical imaging must be understood as decision-support tools rather than autonomous diagnostic authorities, operating under continuous human oversight.

The evolving role of AI in medical imaging demonstrates both the transformative potential and the ethical challenges of algorithmic medicine. While these technologies enhance healthcare professionals' diagnostic capabilities, they also underscore the need to clearly define medical boundaries, preserve clinical decision, and ensure that technological innovation remains aligned with human-centered values in healthcare

3.2 AI in Disease Prediction and Prognosis

Artificial Intelligence has increasingly been applied to disease prediction and prognosis, marking a significant shift in medical practice from reactive diagnosis to proactive, preventive care by analyzing large, heterogeneous datasets, including electronic health records, lifestyle data, and monitoring from wearable devices. The AI-driven predictive models has as a goal to identify patterns associated with disease onset, progression, and clinical outcomes. These eHealth tools support early intervention strategies, risk stratification, and personalized treatment planning, particularly in the management of chronic and complex conditions.

Machine learning models are used to predict the probability of disease development, complications, or treatment response across a range of medical domains, including cardiovascular disease, oncology, diabetes, and neurodegenerative disorders. Prognostic algorithms can help for sure th clinicians in estimating survival rates, identifying high-risk patient groups, and optimizing resource allocation within healthcare systems. By processing vast amounts of data beyond the cognitive capacity of human decision-makers, AI systems offer the potential to enhance clinical foresight and improve long-term patient outcomes.

However, predictive and prognostic applications of AI introduce significant conceptual and ethical challenges. Predictions generated by algorithms are inherently probabilistic rather than deterministic, yet they may be perceived as definitive by clinicians or patients. This creates risks of overreliance on algorithmic outputs, potentially influencing medical decisions, patient expectations, and even self-perception of health status. Moreover, inaccuracies or biases in predictive models—often rooted in incomplete or non-representative training data—can lead to unequal risk assessments and exacerbate existing disparities in healthcare.

The use of AI for disease prediction can also raise critical questions regarding on responsibility and clinical judgment. When a prognostic algorithm suggests a high risk of adverse outcomes, clinicians must determine how to integrate this information into decision-making without undermining patient autonomy or replacing human expertise. The challenge lies in balancing the benefits of anticipatory medicine with the ethical obligation to acknowledge uncertainty, preserve trust, and ensure that predictions serve as supportive insights rather than authoritative verdicts.

As predictive AI systems become more embedded in healthcare practice, it is essential to define clear medical boundaries that govern their use. Human oversight, transparent communication, and ethical reflection are necessary to ensure that prognostic technologies contribute to improved care while respecting the complexity and individuality of human health.

4. ETHICAL CHALLENGES OF AI IN HEALTHCARE

4.1 Ethical and Legal Aspects of Artificial Intelligence in Medical Imaging

Starting with basic concepts, ethics is defined as the ability of an individual to evaluate their actions, distinguish between “good” and “bad,” and act to do “good.” Ethical capacity in healthcare is not limited to adherence to formal rules or professional codes, but also reflects an internal moral orientation shaped by attitudes, motivations, emotions, and values guiding professional behavior (Pellegrino & Thomasma, 1993; Rest, 1986). Within medical ethics, foundational principles include respect for autonomy—understood as the individual’s right to self-determination—as well as honesty, beneficence, non-maleficence, and justice (Beauchamp & Childress, 2019). Consent, confidentiality, and Harm and Benefit, which relate to the goal of medical treatment, should be used to promote health and minimize harm to all patients. With appropriate safeguards in place, some exceptions to the above rule

are justified when the planned medical procedures involve minimal or negligible harm and are likely to benefit others (e.g., non-therapeutic research involving minor interventions, such as blood tests). Fairness and Equity Individuals have the right to fair and unprejudiced treatment and equal access to the full range of health services. Healthcare professionals are often called upon to act in complex situations. The literature notes that healthcare professionals' ethical decisions are shaped not only by codes of ethics but also by other collective practices, such as the "culture" of the service where they work and cultural patterns regarding the role of the healthcare professional. Resorting to formulaic thinking may temporarily relieve a professional's concerns. Still, in the long term, it may deprive them of a sense of satisfaction from their work and the ability to provide optimal care to their patients. The use of Artificial Intelligence (AI) and Machine Learning (ML) in Medical Imaging raises significant ethical and legal challenges, necessitating the development of clear frameworks for transparency, safety, and protection for both patients and healthcare professionals.

4.2 Ethical Aspects

One of the most important ethical concerns in the use of artificial intelligence in healthcare is the protection of patients' privacy and the confidentiality of medical data. Medical images and related health information are highly sensitive, and their collection, storage, and analysis must be carried out with great care and respect for patients' personal data. Clear and transparent procedures are essential, particularly regarding how data are managed, shared, and reused. Patients should be properly informed and able to give meaningful informed consent, especially when their data are used to train or improve artificial intelligence algorithms.

At the same time, data security has become a growing challenge. The increasing digitization of healthcare and the transfer of large volumes of medical data through digital networks raise the risk of data breaches, unauthorized access, and cyberattacks. For this reason, technical safeguards such as encryption, anonymization, and pseudonymization play a crucial role in reducing these risks and in maintaining trust in digital health systems.

Another ethical concern relates to accountability and responsibility. Many AI systems operate as complex or partially opaque models, making it difficult for clinicians to fully understand or explain how certain decisions or recommendations are produced. This lack of transparency can become particularly problematic in cases of misdiagnosis or when AI systems are used to support clinical decision-making, as it complicates the assignment of responsibility.

Finally, algorithmic bias represents a significant ethical challenge. When AI systems are trained on datasets that are incomplete, unrepresentative, or shaped by existing social inequalities, their outputs may be inaccurate or unfair. Such biases can lead to unequal treatment, reinforce existing disparities in healthcare, and undermine principles of fairness and equity. Addressing these risks requires careful dataset selection, continuous monitoring of algorithmic performance, and ongoing ethical oversight to ensure that AI applications contribute to more equitable healthcare rather than reproducing existing injustices.

4.3 Legal Aspects and Regulatory Framework

At the legal level, the application of AI in medical imaging is governed by national and international regulations concerning the protection of personal data and the safety of medical procedures.

In Ethical Considerations in AI-Powered Healthcare, there are several main principles. First are the autonomy & the Doctor-Patient Relationship, and the Informed Consent Challenges. Traditional informed consent involves doctor-patient discussions, but AI's "black-box" nature makes it difficult for physicians to explain how it arrived at a decision, raising concerns about whether proper informed

consent is possible. Also, there are some legal frameworks (e.g., EU regulations) that mandate disclosure when AI is used in patient care, while others (e.g., US law) do not explicitly require it. The level of AI intervention significantly impacts informed consent. It's essential to consider whether patients should be informed about AI use in their care, balancing transparency with the risk of overwhelming them with information.

Another topic is dehumanization, which means the loss of the Human Touch in Medicine. There is potential for over-reliance on AI, which can introduce confirmation bias. Healthcare professionals and researchers must comply with the applicable regulatory framework, ensuring the systems they use are lawful, accurate, and reliable. More specifically, at the European level, there is the General Data Protection Regulation (GDPR) and the new Regulation on Artificial Intelligence (March 2024). This regulation aims to establish a single regulatory framework for high-risk AI systems, including those used for diagnosis and support.

According to the legal and regulatory challenges for Artificial Intelligence in Healthcare, the rapid integration of Artificial Intelligence (AI) into healthcare systems has created complex legal and regulatory challenges, particularly regarding liability, accountability, and governance. Liability and accountability are among the most critical legal concerns when AI-driven systems contribute to patient harm. Three primary perspectives on liability have emerged in the literature and in regulatory discussions: the physician, the institutional, and the developer.

First, physician liability remains the dominant model in current clinical practice because physicians are traditionally held accountable for medical decisions.

Second, institutional liability, the healthcare institutions may bear responsibility if harm results from the implementation, deployment, or inadequate oversight of AI systems. (This includes failures related to insufficient staff training, inappropriate integration of AI tools into clinical workflows, or reliance on systems that have not been adequately validated for specific patient populations)

And, developer liability raises more complex legal questions. The Artificial Intelligence manufacturers and software developers could be held accountable for design flaws, biased training data, or insufficient transparency in algorithmic decision-making. However, legal precedents in this area remain limited, and responsibility is often diffused across multiple actors involved in the development and deployment of AI systems.

5. EFFECTIVE GOVERNANCE OF AI IN HEALTHCARE REQUIRES REGULATORY OVERSIGHT THROUGHOUT THE LIFECYCLE OF AI SYSTEMS. THIS INCLUDES THREE CRITICAL STAGES.

During the research and development phase, regulation should focus on ethical design, mitigation of data bias, and rigorous validation processes. Ensuring that training datasets are representative and that algorithms are tested across diverse populations is essential to prevent discriminatory outcomes and ensure clinical reliability.

The market approval stage represents another key regulatory checkpoint. Approval processes vary across jurisdictions, reflecting different regulatory philosophies and healthcare systems. For example, in the United States, AI-based medical devices are regulated by the Food and Drug Administration (FDA), whereas in the European Union they fall under the Medical Device Regulation (MDR). Other regions, such as Saudi Arabia, operate through national authorities, such as the Saudi Food and Drug Authority (SFDA). These differences create challenges for international harmonization and raise concerns regarding consistency in safety and performance standards.

Finally, this is increasingly recognized as essential, particularly for adaptive AI systems that continue to learn and evolve after deployment. The mechanisms for ongoing monitoring, and accountability are necessary to detect performance degradation, emerging biases, or unintended consequences. The Global initiatives, including governance frameworks proposed by the World Health Organization (WHO), aim to address these challenges by promoting transparency, traceability, and continuous evaluation.

The regulatory approaches to AI in healthcare vary significantly between countries and regions. Some adopt a free-market-oriented model, emphasizing innovation and minimal regulatory constraints to accelerate technological development. Others prioritize strong regulatory frameworks, placing patient safety, data protection, and ethical accountability at the forefront.

In many cases, AI governance is centralized, with government authorities playing a decisive role in approving, monitoring, and regulating high-risk AI applications. These differences reflect broader societal values regarding the balance between innovation and protection, and they complicate efforts to establish universally accepted standards for AI in healthcare.

At the organizational level, healthcare institutions may need to establish internal governance mechanisms, such as specialized committees or subcommittees, to define documentation standards, usage protocols, and accountability structures for AI systems. Clear documentation of how AI tools are used in clinical decision-making can play a crucial role in legal defensibility and patient safety.

Until comprehensive and universally accepted legal guidelines are established, best clinical practice requires that physicians maintain active clinical decision and remain informed about the capabilities and limitations of AI systems. Sole reliance on AI recommendations is unlikely to constitute an adequate legal defense in cases of harm. Instead, AI should function as a supportive instrument within a broader framework of professional responsibility, ethical reasoning, and patient-centered care.

6. MEDICAL BOUNDARIES AND HUMAN OVERSIGHT IN ARTIFICIAL INTELLIGENCE AND EHEALTH

The development and adoption of artificial intelligence (AI) applications in eHealth are fundamentally transforming how healthcare is delivered, monitored, and evaluated. Systems based on machine learning algorithms are now being integrated into electronic health records (EHRs), telemedicine platforms, and digital rehabilitation technologies, enhancing decision-making and personalizing interventions. However, increased automation underscores the need to establish clear medical boundaries and maintain meaningful human oversight (Topol, 2019).

6.1 The role of healthcare professionals in AI-based eHealth systems

In the context of eHealth, the role of physicians and healthcare professionals is being redefined. Clinicians are not merely users of digital systems, but active co-creators of algorithmic logic, participating in the definition of clinically relevant variables, outcome indicators, and safety thresholds for AI systems. Clinical responsibility remains with humans, even when decisions are supported by complex algorithmic models (Shortliffe & Sepúlveda, 2018).

Especially in telemedicine and remote monitoring environments, where direct physical presence is absent, clinical finding serves as a filter for evaluating algorithmic recommendations, ensuring that interventions align with the patient's individual needs and preferences (Cassell, 2020).

6.2 Supervised learning in AI and eHealth applications

Supervised learning is a key technological pillar of AI systems in eHealth, as it utilizes labeled data from EHRs, wearables, and digital rehabilitation platforms. Among the most widely used algorithms are linear regression, logistic regression, decision trees, random forests, and Support Vector Machines (SVM).

Linear regression is widely used to predict continuous clinical indicators, such as the progress of functional rehabilitation or changes in biomarkers collected through telemonitoring systems. Logistic regression is applied to binary decisions, such as the probability of a successful outcome of a digital therapeutic intervention or the need for clinical reassessment.

Decision trees and random forests offer greater adaptability to complex eHealth datasets and can support the classification of patients based on their responses to personalized digital interventions. Similarly, SVMs are used in high-dimensional environments where clinical, functional, and behavioral data are combined. Despite their high performance, the limited interpretability of some models increases the need for human oversight and explainable AI mechanisms (Char et al., 2018).

6.3 Limits of automation and human oversight in eHealth

The widespread use of AI in eHealth comes with technical and ethical challenges. Overfitting, data bias, and reliance on historical datasets can lead to inaccurate or unfair predictions, especially in vulnerable patient populations (Obermeyer et al., 2019). At the same time, the risk of automation bias is amplified in digital environments, where algorithmic recommendations are seamlessly integrated into clinical workflows.

For this reason, international regulatory and ethical frameworks promote “human-in-the-loop” models, according to which healthcare professionals retain ultimate control, the ability to intervene, and responsibility for decisions made with the help of AI (European Commission, 2020). Maintaining this balance is a prerequisite for the sustainable, safe, and socially acceptable use of artificial intelligence in eHealth.

7. SOLUTION AND RECOMMENDATION

As artificial intelligence continues to advance at a remarkable pace, its integration into healthcare systems is becoming increasingly widespread, enabling innovative treatments, enhanced diagnostic accuracy, and more personalized patient care. At the same time, the rapid expansion of AI technologies necessitates the development of comprehensive solutions and policy recommendations that address the ethical and legal challenges identified in previous sections (García-Valiña et al., 2023; Mora, 2025). Without adaptive governance mechanisms, ongoing ethical reflection, and robust legal safeguards, the potential benefits of AI risk are being undermined by issues of mistrust, inequity, and harm.

A central recommendation emerging from the literature is the adoption of human-centered AI frameworks in healthcare. AI systems should be designed as decision-support tools that enhance, rather than replace, clinical decision, ensuring that healthcare professionals retain ultimate responsibility for medical decisions (García-Valiña et al., 2023). This approach reinforces accountability, preserves professional autonomy, and protects the physician–patient relationship, which remains a cornerstone of ethical medical practice. In parallel, continuous education and training of healthcare professionals is essential, enabling clinicians to critically assess algorithmic outputs, understand model limitations, and responsibly integrate AI insights into clinical reasoning (Mora, 2025).

From a regulatory perspective, scholars emphasize the importance of lifecycle-based governance of AI systems. Regulation should extend beyond pre-market approval to include post-deployment

monitoring, auditing, and accountability mechanisms, particularly for systems that evolve through continuous learning (European Union, 2024). Such an approach aligns with emerging international governance models, including recommendations from global health organizations, which highlight the need for transparency, explainability, and risk management throughout the operational lifespan of AI applications.

Ethical and legal considerations become especially pronounced in sensitive clinical domains such as palliative care and end-of-life decision-making. While AI systems may assist clinicians by analyzing large volumes of clinical data and offering prognostic insights, these decisions inherently involve deeply personal, emotional, and value-laden factors that cannot be fully captured by algorithms alone. Ensuring respect for patient autonomy, dignity, and individual preferences requires sustained human involvement, with clinicians acting as ethical agents who contextualize AI-generated recommendations within each patient's unique circumstances (García-Valiña et al., 2023).

Legally, the deployment of AI in such contexts raises complex questions of liability and informed consent. When AI recommendations influence care plans or clinical outcomes, responsibility may be distributed among physicians, healthcare institutions, and AI developers, depending on the nature of system use and oversight. Current legal frameworks, including the General Data Protection Regulation (GDPR) and the European Artificial Intelligence Act, emphasize the need for transparency, accountability, and explicit patient consent when algorithmic systems are involved in medical decision-making (European Union, 2016; European Union, 2024). Strengthening informed consent procedures is therefore critical, ensuring that patients and their families are aware of the role AI plays in shaping diagnostic or therapeutic decisions.

Finally, fostering public trust in AI-driven healthcare requires transparency, ethical accountability, and patient engagement. Clear communication regarding the benefits, limitations, and risks of AI systems is essential to maintaining confidence in digital health technologies. Institutional ethics committees and AI governance subcommittees can further support responsible implementation by establishing internal standards for documentation, monitoring, and ethical review (Mora, 2025).

By implementing these solutions and policy recommendations, healthcare systems can harness the transformative potential of artificial intelligence while ensuring that technological innovation remains aligned with the fundamental values of medicine: beneficence, fairness, responsibility, and respect for human dignity. In this way, AI can function not as a substitute for human care but as a tool that empowers healthcare professionals and enhances patient-centered practice.

8. CONCLUSION

According to Eysenbach & Jadad (2001), the electronic revolution is leading to a new period in healthcare provision. The E-health is defined as the use of information and communication technologies in health-related services and processes (Pagliari et al., 2005).

The integration of Artificial Intelligence (AI) into our lifestyle is certain reality, with a powerful and growing presence in the healthcare sector. Healthcare is a continuously evolving field, and the application of AI tools and ML have the potential to significantly enhance the quality, efficiency, and effectiveness of medical services. Nevertheless, technological advancement in such a sensitive domain that cannot be considered in isolation from the ethical and legal implications that accompany it, especially in the field of Medical Imaging.

The rapid technological developments of last decades have contributed to broader societal transformations, marking the transition from the Industrial Society to the Information Society. In this new

background, knowledge is produced, stored, and utilized on a massive scale. At the same time, the accelerated pace of life and increased human interaction generate both unprecedented opportunities and complex challenges.

The AI and ML play a primary role in modern Medical Imaging by enhancing diagnostic accuracy, enabling early disease detection, and supporting the personalized patient care. The paper studied the fundamental medical imaging techniques such as X-ray imaging, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and positron emission tomography (PET) and nucleus concepts of digital imaging, including pixels and voxels, highlighting their significance in contemporary clinical practice.

In the end, the main goal of artificial intelligence in medicine should not be to replace human decision or weaken relationship between the physician–patient, but rather to support the healthcare professionals, reduce administrative burdens, and enable more individualized and effective patient care. Public faith and acceptance of AI-driven healthcare solutions depend largely on patients’ sense of safety, transparency, and respect for their rights. Therefore, technological improvement must advance in parallel with responsibility and legal safeguards, making sure that artificial intelligence serves as a tool for empowerment and improved care, that respects the traditional health practices rather than a source of dehumanization in modern healthcare systems. The primary goal is to keep the patients safe by using the tools that made by humans.

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2. The Algorithmic Transformation of Hellenic Education A Critical Synthesis of Policy, Pedagogy, and Ethical Governance in Greece (2020–2025)

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Abstract: This chapter explores the integration of artificial intelligence within the Hellenic educational landscape from 2020 to 2025. As Greece undergoes a significant digital shift, the authors analyze national policy frameworks, such as the Digital Transformation Bible and the Blueprint for AI Transformation. The research evaluates the “Digital School” infrastructure, emphasizing its role in bridging geographical and socioeconomic divides. Through theoretical lenses like AI-TPACK and Connectivism, the chapter assesses teacher readiness and pedagogical shifts. Ethical considerations are examined through modern European standards and classical Greek philosophy, advocating for a human-centered approach. The authors identify systemic barriers, including teacher burnout and foundational skill gaps revealed by PISA results. Ultimately, this chapter proposes strategic recommendations to ensure AI acts as a tool for equity rather than exclusion. The primary goal is to provide a comprehensive synthesis of the Hellenic AI strategy for researchers and policymakers.

Keywords: Artificial Intelligence, Digital School, Teacher Readiness, AI-TPACK, Connectivism, Digital Literacy, Ethical Governance, Generative AI, STEM, Adult Education

1. INTRODUCTION

The advent of Artificial Intelligence (AI) has initiated a profound paradigm shift across the global educational landscape, and Greece represents a critical case study of an education system in the midst of radical digital transformation. Historically characterized by a centralized, exam-oriented structure, the Greek educational sector is currently navigating the complexities of integrating AI technologies into its national strategies, pedagogical practices, and governance frameworks.¹ This transformation is not merely a technological update but a fundamental re-evaluation of teaching and learning, occurring at a juncture where Greece aligns its national agenda with broader European Union (EU) mandates for digital competence and societal resilience.¹ The introduction of AI tools, ranging from adaptive learning platforms and intelligent tutoring systems to generative AI assistants, offers significant opportunities to personalize instruction and enhance administrative efficiency; however, these innovations also surface critical challenges regarding digital equity, data ethics, and the preservation of human-centered pedagogical values.¹

2. BACKGROUND

The strategic integration of AI in Greece is anchored in the “Digital Transformation Bible 2020-2025,” which serves as the foundational roadmap for the country’s modernization across all sectors (Hellenic Republic, 2020). Within this framework, education is prioritized as a vertical intervention axis aimed at fostering digital skills and upgrading the technological infrastructure of schools and universities (European Commission, 2024). The recent release of the “Blueprint for Greece’s AI

Transformation” in late 2024 further underscores the institutional commitment to establishing Greece as a regional hub for AI innovation, specifically emphasizing the role of education and research in developing the requisite human capital for an AI-driven economy (Special Secretariat of Foresight, 2024). Understanding how AI reshapes educational strategies in Greece requires a nuanced examination of its implications for curriculum design, teacher training, policy formulation, and the overall culture of learning within the unique Hellenic context (ResearchGate, 2025).

3. MAIN FOCUS OF THE CHAPTER

3.1 National Policy Frameworks and the Strategic Reorientation

The evolution of Greek educational policy toward an AI-integrated model is characterized by a multi-layered approach involving legislative reforms, international partnerships, and large-scale infrastructure projects funded by the EU Recovery and Resilience Facility (RRF). The primary legislative catalyst is the Digital Transformation Strategy, which outlines over 400 specific projects designed to modernize the Greek state (Hellenic Republic, 2020). For the educational sector, this strategy manifests through initiatives that bridge the gap between traditional face-to-face instruction and digital-first methodologies, particularly in response to the catalysts provided by the COVID-19 pandemic (Special Secretariat of Foresight, 2024).

The “Digital Transformation Bible 2020-2025” established the initial momentum for the digitization of Greek schools, primarily through the expansion of gigabit connectivity and the distribution of digital tools. By 2024, this vision evolved with the “Blueprint for Greece’s AI Transformation,” developed by a High-Level Advisory Committee under the Prime Minister (Special Secretariat of Foresight, 2024). This blueprint moves beyond general digitization to address the specific nuances of AI, advocating for the introduction of AI-related subjects across all educational levels and the establishment of a National AI Research Institute (Lambadarios, 2025). Table 1 outlines the primary policy instruments guiding this transformation.

Table 1. Primary policy instruments for AI in Greek education

Policy Instrument	Primary Objective	Key AI-Related Interventions
Digital Transformation Bible (2020-2025)	Holistic modernization of the Greek state	Connectivity expansion and digital skills training.
Greece 2.0 (RRP)	Post-pandemic resilience	Funding for «Digital School II» and interactive systems.
Blueprint for AI (2024)	Strategic innovation hub	K-12 AI introduction and Center of Excellence.
Law 5128/2024	Legal foundation for Digital School	Regulation of digital tutoring and live platforms.

Source: (Hellenic Republic, 2020; Special Secretariat of Foresight, 2024)

The Blueprint emphasizes that strengthening education and research is the essential foundation for advancing knowledge in the AI sector. It proposes a collaborative ecosystem where government agencies, universities, and private sectors co-develop AI solutions, ensuring that the Greek educational system does not merely consume foreign technologies but contributes to their development. This approach reflects a broader effort to align national needs with global trends while addressing specific national challenges, such as the digital divide and the demographic decline.

3.2 International Partnerships: OpenAI for Greece

In a landmark move, the Greek government formalized a partnership with OpenAI in September 2025, positioning Greece as one of the first countries globally to integrate specialized academic AI tools into its national secondary education system.²¹ This partnership, involving the Ministry of Education, the Onassis Foundation, and Endeavor Greece, centers on a pilot program for upper-secondary school teachers. The pilot aims to build AI literacy among educators, enabling them to use generative AI for administrative productivity and responsible classroom integration.

The “OpenAI for Greece” initiative operates on two tracks: AI for Education and AI for Innovation. The education track focuses on the safe and ethical deployment of “ChatGPT Edu,” a version of OpenAI’s technology designed for academic institutions, which maintains enterprise-grade security and GDPR compliance. The innovation track includes a Greek AI Startup Accelerator, designed to leverage Greece’s high percentage of STEM graduates—one of the highest in Europe—to foster local innovation and combat “brain-drain” by creating domestic opportunities for AI developers. This partnership represents a shift from theoretical planning to practical, large-scale implementation, signaling Greece’s ambition to be an early adopter of generative AI in public education.

3.3 Infrastructural Evolution: The Digital School Paradigm

The “Digital School” initiative serves as the central platform for the integration of technology in Greek primary and secondary education.¹⁴ Regulated by Law 5128/2024 and funded by the RRF, the platform addresses the geographical challenges of Greece, particularly for students in remote islands and mountainous regions where specialized teachers may be in short supply.¹⁴ The platform’s components, such as Digital Tutoring and Live Tutoring for National Exams, represent a significant departure from the traditional classroom model and seek to provide equal access to high-quality educational resources.

3.4 Digital Tutoring and Live Interactive Sessions

The Digital Tutoring component offers a vast collection of video-based lessons on core subjects like mathematics and language, allowing for personalized learning pathways.¹⁴ These “learning objects”—small units of learning ranging from 2 to 15 minutes—can be used and reused to support various student needs. For third-grade upper secondary students, the Live Tutoring sessions provide real-time interaction with experienced educators, specifically targeted at university entry exam preparation (Panhellenic exams). In the first phase, 19 courses in high schools and 26 courses in vocational schools (EPAL) were introduced, supported by a specialized team of 79 teachers.

This initiative aims to democratize access to high-quality supplementary education, which has historically been a significant financial burden for Greek families who rely on private tutoring (*frontistiria*). By offering these resources for free, the state aims to level the playing field and mitigate socioeconomic disparities in academic achievement. Furthermore, an AI-powered digital assistant, set to launch in the 2025-2026 school year, will analyze student responses to identify learning gaps and recommend personalized study plans, integrating machine learning algorithms with the repository of 15,000 interactive exercises and 7,500 videos.

3.5 Interactive Whiteboards and Classroom Enrichment

A massive investment has resulted in the installation of more than 36,000 interactive learning systems in schools nationwide.¹⁴ These interactive whiteboards (IWBs) are intended to enrich the learning

experience by providing multimodal stimuli—combining visual, auditory, and interactive elements. Research on IWB implementation in Greek classrooms suggests that these tools act as mediators of interaction, providing a scaffold for interpersonal transactions and encouraging student participation. However, the pedagogical effectiveness of IWBs depends heavily on how teachers manage the concurrent presentation of different modes and navigate student engagement, rather than on the hardware itself.

Component of Digital School	Primary Function	Target Audience
Digital Tutoring	On-demand video tutorials on core subjects (Math, Language).	Secondary students (expanding to Primary).
Live Tutoring	Real-time digital lessons for university entry exams.	3rd Grade Upper Secondary and EPAL students.
eParents App	Real-time communication on grades, absences, and meetings.	Parents and guardians nationwide.
AI Digital Assistant	Gap identification and study material recommendation.	Middle and Senior High school students.
Interactive Whiteboards	Multimodal classroom instruction and enrichment.	Students and teachers in K-12 classrooms.

3.6 Theoretical Frameworks and Pedagogical Reimagining

Understanding the impact of AI on Greek education requires a robust theoretical grounding that accounts for the interaction between technology, pedagogy, and content. The academic discourse in Greece has increasingly utilized frameworks like TPACK (Technological Pedagogical Content Knowledge) and Connectivism to analyze how educators navigate this new landscape.

3.7 The Evolution of AI-TPACK

The TPACK framework, originally proposed by Mishra and Koehler (2006), posits that effective technology integration requires a deep understanding of how technological tools intersect with subject matter and instructional methods. In the context of AI, researchers have expanded this to the AI-TPACK framework, which introduces AI-Technological Knowledge (AI-TK) as a distinct domain. This framework suggests that educators must not only know how to use AI tools but also understand their underlying logic—such as machine learning algorithms, natural language processing, and the “black-box” nature of deep learning—to effectively integrate them into specific disciplines like mathematics or language arts.

Research among Greek teachers suggests that while many possess foundational content and pedagogical knowledge, their AI-TK is often limited, creating a significant gap in their overall AI-TPACK.¹⁷ The transition from traditional ICT tools to AI requires a more sophisticated level of technological literacy, as AI tools are autonomous and adaptive, unlike static software.³¹ This underscores the need for professional development that does not merely teach technical operation but focuses on the pedagogical affordances of AI—its ability to provide personalized feedback, generate diverse content, and simulate complex scenarios.

3.8 Connectivism and Learning Networks

Connectivism provides a lens to view learning as a process of network creation in the digital era. In an AI-augmented environment, AI tools can be seen as both “nodes” (sources of knowledge) and “links” (facilitators of connections between learners, resources, and peers). For Greek students, particularly those in remote areas using the Digital School platform, AI-driven systems help traverse these networks, bridging the gap between local classroom constraints and global information repositories. This perspective shifts the focus from rote memorization to the ability to construct and traverse networks of connections, which is essential for succeeding in a society where knowledge is distributed across digital systems.

3.9 Personalized Learning Path Recommendation

AI’s most significant impact on the Greek classroom is the potential for personalized learning, which challenges the traditionally rigid and standardized curriculum. Adaptive learning systems analyze student data in real-time to tailor instruction to individual learning styles, paces, and needs. This evolution is characterized by several development stages:

1. Early Stage: Learning based on historical similarities and basic data mining.
2. Mid-Development: The emergence of knowledge graphs and reinforcement learning techniques to track progress.
3. Current Stage: Multi-technology convergence, where relationship modeling between courses, exercises, and learners allows for highly precise recommendations.

In the Greek context, where classrooms are often heterogeneous, such technologies can provide valuable support in addressing learning disparities. For adult students in Second Chance Schools (SCS), who often balance familial and work obligations, AI offers the flexibility of on-demand access to learning materials, ensuring that education remains accessible despite personal constraints.

3.10 The Human Factor: Teacher Readiness and Challenges

The success of Greece’s AI strategy depends heavily on the readiness and willingness of its teaching workforce. Research indicates a state of “cautious optimism” among Greek educators, who recognize the potential benefits of AI while simultaneously harboring significant concerns about its risks, ethical implications, and their own lack of training.

3.11 Acceptability Models and Motivational Barriers

Statistical surveys of teachers in Greece reveal that while a majority (over 84%) express a willingness to integrate AI, actual usage remains limited. Using models like the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), researchers have identified Perceived Usefulness (PU) as the most significant predictor of a teacher’s intention to use AI tools. If Greek teachers perceive the tools as beneficial to their teaching outcomes and students’ engagement, they are much more likely to adopt them.

Other factors include Personal Innovativeness (PI)—the teacher’s openness to new experiences—and Social Influence (SI), the positive opinions of colleagues and the broader academic community. Interestingly, “Facilitating Conditions” (such as technical infrastructure) yielded no significant direct effect on behavioral intention in some Greek studies, suggesting that pedagogical advantages may be more important to Greek educators than the ease of technical access, even when infrastructure is relatively basic.

3.12 Issues, Controversies, Problems

Despite the strategic drive, several critical issues threaten the success of AI integration in Greece. In higher education, the State often prioritizes institutional autonomy over the protection of individual rights, and the regulatory landscape is described as fragmented (ResearchGate, 2025).

Teacher Readiness and Burnout:

Research indicates a state of “cautious optimism” among Greek educators, who recognize the potential benefits of AI while harboring significant concerns about its risks and their own lack of training (Asderaki et al., 2023). A critical challenge is “burnout,” particularly following the rapid shift to remote learning during the pandemic. Table 2 presents the distinct teacher profiles identified in recent Greek studies.

Table 2. Greek K-12 teacher profiles and readiness

Teacher Profile	Characteristics	Readiness for AI Integration
Skeptically Exhausted	High burnout, low institutional trust.	Low; views AI as a complex workload.
Realistically Cautious	Moderate burnout, focused on constraints.	Moderate; requires proof of value.
Optimistically Engaged	High well-being, readiness for innovation.	High; views AI as an opportunity.

Source: (Asderaki et al., 2023)

Socioeconomic Dynamics and Inequity:

A central pillar of AI strategies must be equitable access. PISA 2022 results highlight structural challenges: 47% of mathematics students fail to reach minimum proficiency, and 60% of eighth-graders do not reach basic digital skill levels (European Commission, 2024). Greece faces an “urban-rural divide,” where penetration and usage quality vary significantly between urban centers and remote islands or mountainous regions (European Commission, 2025).

Ethical Sovereignty and Governance:

The National Commission for Bioethics and Technoethics emphasizes that AI should never replace the human faculty of critical data processing (Bioethics Commission, 2025). There are concerns regarding data privacy in an ecosystem characterized by fragmented frameworks, where global data companies may act as “hidden” managers of the educational landscape (ResearchGate, 2025).

3.13 The Risk of Alienation

A unique perspective in the Greek academic discourse involves the use of Marx’s theory of alienation to examine the integration of AI. Some scholars argue that algorithmic governance and data-driven performance regimes threaten teacher autonomy and creativity. AI can exacerbate four forms of alienation for educators:

- From the Product of Labor: AI-generated lesson plans and assessments may distance teachers from their creative output.

- From the Educational Process: Automated systems may reduce teaching to the management of data flows rather than a relational practice.
- From Professional Identity: The fear of being replaced by machines can undermine the educator’s sense of purpose (species-being).
- From Interpersonal Relations: Diminished human interaction can affect the essential bond between teacher and student.

This underscores the importance of a human-centered approach that champions “augmentation over automation,” ensuring that technology empowers rather than supplants the educator.

3.14 Socioeconomic Dynamics and the Geography of Inequity

A central pillar of the AI related educational strategies in Greece must be equitable access to digital resources. Despite the widespread distribution of interactive whiteboards and digital devices, deep-seated socioeconomic and geographical disparities persist, threatening to widen the educational divide.

3.15 The Urban-Rural Divide and Infrastructure Constraints

Greece’s geography presents significant challenges for infrastructure deployment. While 100% of organized communities have access to 100 Mbps connectivity, the actual penetration and usage quality vary widely between urban centers like Athens and rural, mountainous, or island regions. In rural Greece, demographic aging and gaps in digital skills pose additional hurdles to the digital transition. Statistics show that while early school leaving has dropped significantly in rural areas, geographical imbalances remain prevalent, with some regions showing rates up to four times higher than the national average.

The “Digital School” platform’s specific initiative for remote areas—combining the physical presence of specialized teachers with live digital lessons—is a direct response to these imbalances. However, the success of such initiatives depends on maintaining a balanced approach between remote and blended learning to prevent the total removal of the “human presence,” which is essential for student motivation and mental well-being.

4. SOLUTIONS AND RECOMMENDATIONS

To deal with the identified issues, the authors propose a coherent Hellenic AI strategy based on human-centered augmentation.

- 1. Comprehensive Teacher Support:** Moving beyond ad hoc workshops to continuous training that integrates AI-Technological Knowledge (AI-TK) with Pedagogical Content Knowledge (PCK) (MDPI, 2024).
- 2. The Digital School Infrastructure:** The “Digital School” initiative serves as a central platform to address geographical challenges. Key components are shown in Table 3.
- 3. Ethical Governance:** Establishing a unified educational platform with clear, enforceable standards through the Hellenic Data Protection Authority (DPA) to balance academic autonomy with individual rights (ResearchGate, 2025).

Table 3. Key components of the Digital School platform

Component	Primary Function	Target Audience
Digital Tutoring	On-demand video tutorials on core subjects.	K-12 students nationwide.
Live Tutoring	Real-time sessions for Panhellenic exams.	Upper secondary students.
AI Assistant	Learning gap identification (launch 2025).	Middle and High school students.
Interactive Systems	Installation of 36,000 multimodal whiteboards.	K-12 classrooms.

Source: (Cedefop, 2024; Sparkworks, 2025)

4.1 PISA Results and Basic Skills Gap

The 2022 PISA results highlight structural challenges for the Greek education system. Greece has one of the highest rates of underachievement in mathematics among 15-year-olds in the EU, with 47% failing to reach minimum proficiency. Furthermore, 60% of Greek eighth-graders do not reach the basic level of digital skills, far above the EU average of 43% and the 2030 target of 15%.

Skill Category	Greek Performance (2022 PISA/EU Data)	EU Target / Average
Mathematics Underachievement	47%.15	29.5%.15
Digital Skills Underachievement (8th Grade)	60%.15	15% (2030 Target).15
Early School Leavers	3% (2024).15	< 9%.15
STEM Graduates (Bachelor's)	30%.20	~23% (OECD Avg).20

These statistics reveal a paradox: while Greece has a high rate of STEM graduates and a low rate of early school leaving, it struggles with the development of basic digital and mathematical competencies among the general student population. AI-related strategies must therefore focus on using technology to bridge these foundational skill gaps, rather than just introducing advanced tools for high-performing students.

4.2 Ethical Sovereignty and Governance

The integration of AI necessitates a comprehensive policy framework that addresses data ethics, privacy, and algorithmic transparency. Greece is currently working to harmonize its national strategy with the European Union framework for digital transformation, including the EU AI Act and the GDPR.

4.3 The National Commission for Bioethics and Technoethics

The National Commission for Bioethics and Technoethics has issued critical opinions on the responsible implementation of AI in Greek schools. The Commission emphasizes that the social function of education must remain unquestioned, and AI should never replace the human faculty of critical data processing or the free development of a student's personality. Key ethical principles adopted for the Greek context include:

- **Respect for Human Dignity:** Excluding AI applications that manipulate student behavior, implement "social scoring," or leak behavioral data to third parties.

- Principle of Autonomy: Evaluating AI tools based on whether they support responsible self-determination and enhance critical thinking rather than providing “ready-made solutions”.
- Principle of Justice and Equity: Ensuring that AI does not reproduce discrimination (e.g., gender or racial bias) and that students from all socioeconomic backgrounds have equal opportunities to use technology creatively.
- Transparency and Accountability: Ensuring that AI-generated outputs are explainable and that a human body (teacher or administrator) remains responsible for any AI-driven decisions.

4.4 Data Privacy in an Unstable Ecosystem

Greek researchers have identified several regulatory challenges in the country’s digital education ecosystem, describing it as “unstable” and characterized by fragmented frameworks. While the COVID-19 pandemic forced a rapid shift to remote learning, lessons from security lapses during that period have not been fully integrated into proactive national standards. One significant concern is that database software packages and global data companies act as “hidden” managers of the educational landscape, prioritizing their own commercial interests over the fundamental rights of learners.

To address these challenges, Greece must establish a unified educational platform with clear, enforceable standards through the Hellenic Data Protection Authority (DPA). This would balance the institutional autonomy of universities with the protection of individual privacy rights, ensuring that the integration of AI aligns with democratic values and social justice principles.

4.5 Philosophical Reflections: Revisiting Ancient Wisdom for the AI Era

A unique dimension of the Greek discourse on AI in education is the revisit of classical philosophical principles to guide modern ethical implementation. Scholars argue that the ancient concepts of *Paidéia* (holistic education) and *Kalokagathia* (the balance of beauty and goodness) offer valuable insights for a balanced, health-oriented approach to student development in an age of intense digitization.

4.6 Plato’s Allegory of the Cave and AI Literacy

Plato’s Allegory of the Cave takes on new relevance as a metaphor for the risks of generative AI. Just as the prisoners in the cave mistake shadows for reality, modern students may mistake AI-generated “hallucinations” or biased summaries for ultimate truth. This underscores the importance of developing AI literacy, enabling students to critically evaluate AI content and move toward the “light” of authentic understanding through careful Socratic questioning and historical-philological source criticism. Furthermore, Plato’s emphasis on the integration of physical conditioning and intellectual training reminds us that modern educational systems should not neglect bodily health and social interaction in favor of purely intellectual or digital learning.

4.7 Aristotle’s Virtue Ethics and Character Education

Aristotle’s belief that virtues are developed through practice and habit, rather than simple acquisition of knowledge, poses a challenge for AI-driven education. While AI can efficiently deliver information and personalize learning paths, it cannot replace the human role in character education. The development of virtues like courage (*andreia*), balance (*sofrosyne*), and excellence (*areté*) requires a human-centered environment where ethical dilemmas are navigated through lived experience and empathy—traits that AI cannot currently replicate. Therefore, the Greek model advocates for an “aug-

mented” pedagogy where AI handles the data-intensive tasks of information retrieval and personalized pacing, while human educators focus on the cultivation of moral and civic skills.

Synthesis: Towards a Coherent Hellenic AI Strategy

The impact of Artificial Intelligence on educational strategies and policies in Greece is multifaceted, encompassing technological, pedagogical, ethical, and social dimensions. The transformation of the Greek education system is marked by an institutional drive toward modernization, yet it is constrained by historical exam-centrism, infrastructural disparities, and the psychological readiness of its teaching workforce.

Key Strategic Recommendations for Policy and Practice

Comprehensive Teacher Support: Moving beyond ad hoc workshops to continuous, professionalized training that integrates AI-Technological Knowledge (AI-TK) with Pedagogical Content Knowledge (PCK).¹⁷ Policy should prioritize well-being and institutional trust to engage “Skeptically Exhausted” teachers.

Bridging the Foundational Skills Gap: Leveraging AI tools not just for high-performing students but as adaptive interventions to address the significant underachievement in mathematics and digital literacy highlighted by PISA results.

Ethical Leadership and Governance: Establishing clear national guidelines for data protection and algorithmic transparency, led by a collaborative task force of the Ministry of Education, the Bioethics Commission, and the Data Protection Authority.

Promoting “Augmentation over Automation”: Maintaining the irreplaceable role of the human educator by using AI to reduce administrative burdens and support personalized pacing, while refocusing the curriculum on critical thinking, creativity, and moral development.

Addressing the Rural Divide: Ensuring that the “Digital School” platform does not replace the human teacher in remote areas but supports them through high-quality digital resources and blended learning formats.

In conclusion, the future of Greek education in an AI-augmented world depends on the capacity of policymakers and educators to harness technology responsibly—balancing rapid innovation with the human-centered values rooted in both European democratic principles and the ancient Hellenic philosophical tradition. By fostering a coherent national strategy that integrates AI into teaching and learning, Greece can ensure that technology serves as a tool for empowerment and inclusion rather than a mechanism for social exclusion. The shift from rote learning to critical, digital, and ethical literacy is not just a technological necessity but a moral imperative for preparing the next generation of Greek citizens for the evolving challenges of the digital society.

5. FUTURE RESEARCH DIRECTIONS

Future research should explore the longitudinal impact of the “OpenAI for Greece” pilot program, which launched in 2025 to provide ChatGPT Edu access to secondary teachers (Greek News Agenda, 2025). Investigations are required to determine if AI-driven personalized learning paths effectively bridge the mathematical proficiency gaps highlighted by PISA results (European Commission, 2024). Furthermore, scholars should examine how the ancient concepts of *Paideia* and *Kalokagathia* can be integrated into modern AI ethics to foster a more balanced approach to student development (Frontiers, 2025).

6. CONCLUSION

The transformation of the Greek education system is marked by an institutional drive toward modernization, yet it is constrained by historical exam-centrism and infrastructural disparities. The successful future of Greek education in an AI-augmented world depends on the capacity to harness technology responsibly—balancing rapid innovation with the human-centered values rooted in both European democratic principles and the ancient Hellenic tradition. By fostering a strategy that integrates AI into teaching while protecting student autonomy, Greece can ensure that technology serves as a tool for empowerment rather than a mechanism for social exclusion.

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KEY TERMS AND DEFINITIONS

AI-TPACK: A framework describing the types of knowledge required by teachers for the successful integration of artificial intelligence in teaching.

Connectivism: A learning theory for the digital era that highlights the significance of relationships and networks in the knowledge-acquisition process.

Digital School: A comprehensive Greek national platform providing digital tutoring, live interactive lessons, and repositories for K-12 students.

Digital Transformation Bible: The primary strategic roadmap for modernizing the Greek state and society through digital technologies (2020-2025).

Hellenic Education: The formal educational system of Greece, traditionally characterized by centralized governance and high-stakes national exams.

OpenAI for Greece: A national partnership between the Greek government and OpenAI to integrate academic AI tools into secondary education.

Paideia: The ancient Greek concept of holistic education aimed at shaping well-rounded, virtuous citizens.

Panhellenic Exams: The high-stakes national examinations in Greece used to determine university entrance.

3. Digital Transformation in Higher Education: Emerging Technologies, Governance Challenges, and the Integration of Artificial Intelligence

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Abstract: Digital technologies have transformed educational institutions by enabling efficient administrative processes, data-driven decision-making, and personalized learning experiences. The integration of learning management systems, cloud-based platforms, and analytics tools allows schools and universities to optimize resources, monitor student performance, and extend educational access beyond physical boundaries. This transformation is significant because it reshapes how knowledge is delivered and assessed, making education more responsive to individual learner needs and societal demands. As digital infrastructure expands and data generation grows exponentially, the adoption of advanced technologies in education will accelerate in the coming years. The proliferation of educational data provides the foundation for training sophisticated artificial intelligence systems, while advances in computational architectures, particularly Transformer models and attention mechanisms, are producing AI tools of unprecedented capability. The present paper documents the current state of digital transformation in higher education through a systematic review of recent literature, examining the technologies driving change, the barriers impeding progress, and the governance frameworks necessary for successful implementation. Furthermore, this work explores the emerging role of artificial intelligence, demonstrating how AI is poised to become the defining technology of the next decade, capable of personalizing instruction at scale and fundamentally altering the educational landscape. The findings indicate that realizing the benefits of digital transformation requires sustained investment, ethical frameworks addressing data privacy and algorithmic bias, and strategic approaches that ensure technology serves educational objectives.

Keywords: digital transformation, higher education, artificial intelligence, educational governance, Transformer architecture, data-driven decision-making

1. INTRODUCTION

The educational landscape has undergone profound changes over the past two decades, driven primarily by the rapid advancement and adoption of digital technologies. Higher education institutions across the globe are increasingly recognizing that digital transformation is not merely an option but a strategic imperative for maintaining relevance and competitiveness in the contemporary academic environment. The term digital transformation refers to the integration of digital technology into all areas of an organization, fundamentally changing how it operates and delivers value to stakeholders (Verhoef et al., 2021). In the context of higher education, this transformation encompasses everything from administrative processes and student services to pedagogical approaches and research methodologies. Universities and colleges are now expected to provide seamless digital experiences that meet the evolving expectations of students, faculty, and staff while simultaneously addressing the demands of an increasingly interconnected global society. The scope of this transformation extends beyond the mere digitization of existing processes and requires a fundamental rethinking of institutional strategies, governance structures, and operational frameworks.

Understanding the concept of digital transformation requires a clear distinction between digitization, digitalization, and digital transformation itself. Digitization refers to the conversion of analog

information into digital formats, such as scanning paper documents into electronic files. Digitalization goes a step further by using digital technologies to change business processes and create new value-generating opportunities. Digital transformation, however, represents the most profound level of change, involving a complete reimagining of how an organization functions and delivers value through the strategic integration of digital capabilities (Morakanyane et al., 2017). In higher education, this means transforming not only the administrative backbone of institutions but also the very nature of teaching, learning, and research. The transformation affects how students interact with educational content, how faculty members design and deliver courses, how administrators manage institutional resources, and how institutions engage with external stakeholders including employers, government bodies, and the broader community.

The governance of higher education institutions has traditionally been characterized by hierarchical structures, deliberative decision-making processes, and a strong emphasis on academic freedom and institutional autonomy. However, the digital age has introduced new imperatives that challenge these traditional governance models. Digital governance in education refers to the use of digital technologies to enhance the efficiency, transparency, and accountability of institutional management and decision-making processes (Gkrimpizi et al., 2024). This includes the implementation of enterprise resource planning systems, learning management systems, student information systems, and various other digital platforms that support institutional operations. The shift toward digital governance requires institutions to develop new competencies, establish appropriate policies and frameworks, and cultivate a culture that embraces technological change while preserving the core values of academic inquiry and intellectual freedom. Educational leaders must navigate the complex terrain of technological adoption while ensuring that digital tools serve pedagogical and institutional goals rather than becoming ends in themselves.

Several key technologies are driving the digital transformation of higher education institutions. Cloud computing has emerged as a foundational technology that enables institutions to scale their digital infrastructure flexibly and cost-effectively. Big data analytics allows institutions to gather and analyze vast amounts of information about student performance, institutional operations, and market trends, enabling data-driven decision-making at all levels of governance. Learning analytics specifically focuses on understanding and optimizing learning and the environments in which it occurs. Mobile technologies have made educational resources accessible anytime and anywhere, fundamentally changing how students engage with their studies. Social media platforms have created new channels for communication, collaboration, and community building among students, faculty, and other stakeholders. These technologies, when effectively integrated, create an ecosystem that supports personalized learning experiences, efficient administrative processes, and evidence-based institutional planning (Brooks & McCormack, 2020).

The barriers to digital transformation in higher education are multifaceted and span technological, organizational, cultural, and regulatory dimensions. Technological barriers include inadequate infrastructure, lack of interoperability between systems, and concerns about data security and privacy. Organizational barriers encompass insufficient funding, lack of strategic vision, and inadequate change management practices. Cultural barriers involve resistance to change among faculty and staff, lack of digital literacy, and skepticism about the value of technology in education. Regulatory barriers include restrictive policies, unclear guidelines for data governance, and varying standards across different jurisdictions (Aditya et al., 2021). Addressing these barriers requires a systematic approach that considers the unique context of each institution while drawing on best practices and lessons learned from successful transformation initiatives elsewhere. Institutions must develop comprehensive strat-

egies that address not only the technical aspects of digital transformation but also the human and organizational factors that ultimately determine the success or failure of such initiatives.

The COVID-19 pandemic served as an unprecedented catalyst for digital transformation in higher education. Institutions that had previously been hesitant to embrace digital technologies were forced to rapidly adopt online learning platforms, virtual collaboration tools, and remote administrative processes (Mhlanga et al., 2022). This emergency transition revealed both the potential and the limitations of digital education, highlighting the importance of preparedness, flexibility, and resilience in institutional strategies. The pandemic experience demonstrated that digital transformation is not merely a matter of implementing new technologies but requires fundamental changes in pedagogical approaches, assessment methods, and support systems. It also exposed significant inequities in access to technology and digital skills, underscoring the need for inclusive approaches to digital transformation that address the needs of all students, regardless of their socioeconomic background or geographic location. The lessons learned during this period continue to inform institutional strategies as higher education enters a post-pandemic era characterized by hybrid and flexible learning models.

Artificial intelligence represents the next frontier in the digital transformation of higher education. AI technologies, including machine learning, natural language processing, and computer vision, are beginning to transform various aspects of educational operations, from student recruitment and admission to teaching and assessment (UNESCO, 2024). AI-powered chatbots can provide round-the-clock support to students, answering questions about administrative procedures, academic programs, and campus services. Intelligent tutoring systems can deliver personalized learning experiences that adapt to individual student needs, pacing, and learning styles. Predictive analytics powered by AI can help institutions identify students at risk of dropping out and intervene proactively to support their success. Administrative processes such as scheduling, resource allocation, and compliance monitoring can be automated and optimized using AI algorithms. The integration of AI into higher education governance raises important questions about data privacy, algorithmic bias, transparency, and accountability that institutions must address through appropriate policies and ethical frameworks.

Looking ahead, the trajectory of digital transformation in higher education points toward even deeper integration of technology into all aspects of institutional life. The World Economic Forum (2024) emphasizes that digital transformation is essential for long-term growth and sustainability in the education sector. Emerging technologies such as virtual and augmented reality, blockchain, and the Internet of Things promise to create new possibilities for immersive learning experiences, secure credentialing, and smart campus management. The coming years will likely see AI becoming an embedded feature of educational governance, supporting decision-making processes at all levels from individual student advising to strategic institutional planning. However, realizing this potential will require sustained investment in digital infrastructure, ongoing development of digital competencies among faculty and staff, and thoughtful governance frameworks that balance innovation with ethical considerations. Institutions that successfully navigate this transformation will be well-positioned to thrive in an increasingly digital world, while those that fail to adapt risk becoming irrelevant to the students and societies they serve.

2. RELATED WORK

The academic literature on digital transformation in higher education has grown substantially in recent years, reflecting the increasing importance of this topic for educational policy and practice. Benavides et al. (2020) conducted a systematic literature review that examined the scope and nature of digital

transformation initiatives in higher education institutions globally. Their analysis identified several key themes, including the drivers and barriers of transformation, the technologies being adopted, and the outcomes being achieved. The study found that successful digital transformation requires a holistic approach that addresses technological, organizational, and human factors simultaneously. It also highlighted the importance of leadership commitment, stakeholder engagement, and continuous evaluation in sustaining transformation efforts over time. The findings suggest that institutions should develop comprehensive digital strategies that align technological investments with institutional mission and goals while building the capacity needed to implement and sustain change.

Research by Gkrimpizi et al. (2023) provides a systematic classification of barriers to digital transformation in higher education institutions. Their comprehensive review identified barriers across multiple categories, including technological infrastructure, organizational culture, leadership and governance, human resources, financial constraints, and external environment. The technological barriers encompass issues such as legacy systems, lack of integration between platforms, and cybersecurity concerns. Organizational culture barriers include resistance to change, lack of digital mindset, and insufficient collaboration across departments. Leadership barriers involve lack of strategic vision, inadequate change management, and poor communication of transformation goals. Human resource barriers include insufficient digital skills, lack of training opportunities, and concerns about job displacement. Financial barriers encompass limited budgets, competing priorities, and difficulties in demonstrating return on investment. External barriers include regulatory constraints, vendor dependencies, and rapidly changing technology landscapes. This classification provides a useful framework for institutions to assess their readiness for digital transformation and identify areas requiring attention.

The work of Gkrimpizi et al. (2024) further contributes to the field by defining the meaning and scope of digital transformation in the specific context of higher education institutions. Their research addresses the conceptual ambiguity that has characterized much of the literature, providing a clear definition that encompasses the strategic, operational, and cultural dimensions of transformation. According to their analysis, digital transformation in higher education involves the comprehensive integration of digital technologies across all institutional functions, accompanied by changes in organizational structures, processes, and cultures. This definition emphasizes that transformation is not merely about technology adoption but requires fundamental changes in how institutions think about and deliver their core missions of teaching, research, and service. The study also identifies key success factors for transformation initiatives, including strong leadership support, clear strategic vision, adequate resource allocation, stakeholder engagement, and continuous learning and adaptation.

Examining digital transformation from a practical implementation perspective, Alenezi and Akour (2023) present a case study of Prince Sultan University in Saudi Arabia. Their research describes a comprehensive digital transformation blueprint that addresses infrastructure, platforms, applications, and governance frameworks. The case study illustrates how a university can systematically approach digital transformation through careful planning, phased implementation, and continuous evaluation. Key elements of their blueprint include the establishment of a digital transformation committee, the development of a strategic roadmap, the implementation of enterprise systems, and the creation of support structures for faculty and students. The study demonstrates the importance of aligning digital initiatives with institutional strategic plans and engaging stakeholders throughout the transformation process. Lessons learned from this case include the need for flexibility in implementation, the value of pilot projects for testing new approaches, and the importance of celebrating successes to build momentum for further change.

The relationship between digital transformation and digital literacy has been explored by Farias-Gaytan et al. (2023) in their systematic literature review. Their research examines how higher education institutions can develop digital literacy among students and staff as a foundation for successful digital transformation. The study identifies different dimensions of digital literacy, including information literacy, media literacy, communication literacy, and technology literacy. It also explores the role of institutional policies and practices in fostering digital literacy development. The findings suggest that digital literacy is both a prerequisite for and an outcome of digital transformation, creating a virtuous cycle in which technological adoption drives skill development and enhanced skills enable more sophisticated use of technology. The research emphasizes the importance of embedding digital literacy development into curricula and professional development programs rather than treating it as an add-on activity.

Several studies have examined the attitudes of key stakeholders toward digital transformation in higher education. Alhubaishy and Aljuhani (2021) investigated the challenges faced by instructors and students in Saudi universities during digital transformation initiatives. Their research identified significant attitudinal barriers among both groups, including concerns about the quality of online education, difficulties in adapting to new teaching and learning methods, and anxieties about technological failures. The study found that students generally held more positive attitudes toward digital transformation than faculty members, possibly reflecting generational differences in technology familiarity and comfort. However, both groups expressed concerns about the potential loss of face-to-face interaction and the challenges of maintaining engagement in digital learning environments. The research suggests that addressing attitudinal barriers requires comprehensive communication strategies, adequate training and support, and opportunities for stakeholders to participate in shaping transformation initiatives.

The ambivalence experienced by university teachers regarding digital transformation has been explored by Sjoberg and Lilja (2019). Their qualitative research reveals the complex emotions and conflicting views that faculty members hold about technological change in higher education. On one hand, teachers recognize the potential benefits of digital technologies for enhancing teaching effectiveness, expanding access to education, and enabling new forms of scholarly communication. On the other hand, they express concerns about the impact of technology on academic values, the commodification of education, and the changing nature of the teacher-student relationship. This ambivalence reflects deeper tensions within higher education between traditional academic cultures and the pressures of modernization and efficiency. The study suggests that successful digital transformation requires acknowledging and addressing these concerns rather than dismissing them as mere resistance to change.

The impact of the COVID-19 pandemic on digital transformation in higher education has been documented by multiple researchers. Mospan (2022) examines the emergency digital transformation that occurred in universities during the pandemic, identifying trends, challenges, and lessons learned. The study highlights how institutions were forced to rapidly scale up their digital capabilities, often implementing in weeks what might otherwise have taken years. While this accelerated transformation demonstrated the resilience and adaptability of higher education institutions, it also exposed significant gaps in digital infrastructure, faculty preparedness, and student support systems. Mhlanga et al. (2022) focus specifically on the South African context, analyzing the key lessons from the pandemic experience for digital transformation in that country. Their research emphasizes the importance of addressing digital divides and ensuring that digital transformation initiatives promote rather than undermine educational equity.

Research on organizational readiness for digital transformation has been conducted by Budiyan-to et al. (2024), who examined the barriers and readiness factors affecting digital transformation in higher education. Their study identifies key dimensions of organizational readiness, including technological readiness, organizational readiness, environmental readiness, and individual readiness. Technological readiness encompasses the availability and quality of digital infrastructure and platforms. Organizational readiness involves factors such as leadership commitment, strategic alignment, and resource availability. Environmental readiness considers external factors such as government policies, industry trends, and competitive pressures. Individual readiness addresses the skills, attitudes, and motivations of faculty and staff. The research provides a framework for assessing institutional readiness and developing targeted interventions to address identified gaps.

The potential negative consequences of digital transformation have been explored by researchers concerned about the dark side of technological change. Garcia-Penalvo (2021) provides an institutional reference framework for eLearning that aims to help institutions avoid the pitfalls of poorly planned digital transformation. The framework identifies risks such as the erosion of educational quality, the marginalization of certain student groups, and the loss of the humanistic values that underpin higher education. Maurya and Yadav (2024) specifically examine the dark side of digital transformation in online teaching and learning, highlighting issues such as increased workload for faculty, student disengagement, and the challenges of maintaining academic integrity in digital environments. These studies serve as important reminders that digital transformation must be approached critically and that technological adoption should be guided by educational values rather than technological determinism.

Methods for assessing and managing digital transformation have been proposed by several researchers. Marks and AL-Ali (2020) developed a framework for maturity assessment that allows institutions to evaluate their progress along the digital transformation journey. Their framework identifies different maturity levels, from initial digitization efforts to fully transformed digital organizations, and provides indicators for each level across multiple dimensions. Rodriguez-Abitia and Bribesca-Correa (2021) similarly focus on assessment methods for digital transformation in universities, proposing tools and metrics for evaluating transformation progress and outcomes. Diaz-Garcia et al. (2023) present a case study of managing digital transformation in a higher education institution, illustrating the challenges and strategies involved in leading large-scale organizational change. These assessment and management frameworks provide practical guidance for institutions seeking to plan, implement, and evaluate their digital transformation initiatives.

Regional perspectives on digital transformation provide insights into how context shapes transformation processes and outcomes. Tri and Hoang (2023) examine the impact of digital transformation in Vietnamese higher education, highlighting the unique challenges and opportunities faced by institutions in developing country contexts. Adamu (2024) focuses on the digitalization of higher education in Ethiopia, exploring how institutions in less-resourced environments can pursue digital transformation despite infrastructure and capacity constraints. Bucata et al. (2022) provide a broader analysis of digital transformation in the higher education system, examining trends across different national contexts. Grodek-Szostak et al. (2024) specifically address digital transformation in adult education organizations, extending the discussion beyond traditional higher education institutions. These regional and contextual studies highlight the importance of adapting digital transformation strategies to local conditions while learning from international best practices.

The development of agile approaches to digital transformation has been explored by Sararuch et al. (2023), who propose an agile enterprise architecture for digital transformation in higher educa-

tion institutions. Their research argues that traditional, top-down approaches to transformation are inadequate in rapidly changing technological environments and that institutions need more flexible, iterative approaches that can adapt to emerging opportunities and challenges. The agile architecture they propose emphasizes responsiveness, continuous improvement, and stakeholder involvement in transformation processes. This approach aligns with broader trends in organizational management toward agility and adaptive capacity. The integration of agile principles into digital transformation strategies represents a promising direction for institutions seeking to navigate the uncertainties of technological change while maintaining alignment with their core educational missions.

International organizations have also contributed significantly to the discourse on digital transformation in education. The OECD (2024) provides policy guidance on digital transformation, emphasizing the importance of coordinated approaches across education systems and the need for governments to support institutional transformation efforts. UNESCO (2024) addresses digital learning and the transformation of education from a global perspective, highlighting both the opportunities for expanding access to quality education and the risks of exacerbating existing inequalities. The World Economic Forum (2024) focuses on accelerating digital transformation for long-term growth, connecting educational transformation to broader economic and social development goals. Aditya and Suranto (2024) examine the role of educational transformation in improving student quality in the digital era, linking transformation processes to educational outcomes. These contributions from international organizations and policy researchers provide important context for understanding digital transformation as a global phenomenon with significant implications for educational equity and quality.

3. ARTIFICIAL INTELLIGENCE AND THE FUTURE OF EDUCATION: TRANSFORMATIVE TECHNOLOGIES AND EMERGING PARADIGMS

The emergence of artificial intelligence as a transformative force in education represents a paradigm shift that is fundamentally altering how knowledge is created, disseminated, and acquired. Unlike previous technological innovations that primarily enhanced existing educational processes, AI technologies are capable of redefining the very nature of teaching and learning. The rapid advancement of AI systems, particularly large language models and generative AI tools, has created unprecedented opportunities for personalized instruction, automated assessment, and intelligent tutoring at scale. Educational institutions worldwide are now confronting the reality that AI will not merely supplement traditional pedagogical approaches but will increasingly become an integral component of the educational ecosystem (Garzon et al., 2025). This transformation is occurring against the backdrop of massive digital data generation within educational environments, providing the raw material necessary for training increasingly sophisticated AI systems. The convergence of abundant data, advanced computational infrastructure, and breakthrough algorithmic architectures has positioned AI as the defining technology of the coming decade in education.

The foundation of modern AI capabilities in education rests upon the unprecedented volume of digital data that educational institutions now generate and collect. Every interaction within learning management systems, every submission through digital platforms, every query posed to educational databases, and every assessment completed online contributes to vast repositories of educational data. This data encompasses student performance metrics, learning behavior patterns, engagement indicators, and content interaction logs that collectively provide rich insights into the learning process. The availability of such comprehensive datasets has enabled the training of AI models that can

understand educational contexts with remarkable sophistication. Machine learning algorithms require substantial training data to develop accurate predictive capabilities and generate meaningful outputs, and the digital transformation of education has provided precisely this resource (Zhang et al., 2025). As educational institutions continue to digitize their operations and expand online learning offerings, the volume of available training data grows exponentially, creating a virtuous cycle in which more data enables better AI systems, which in turn generate more valuable data through their deployment.

The technological breakthroughs underlying contemporary AI systems stem primarily from innovations in neural network architectures, most notably the Transformer architecture and its attention mechanisms. The Transformer model, introduced in 2017, revolutionized natural language processing by enabling models to process sequential data in parallel while maintaining contextual awareness across long text sequences. The attention mechanism at the core of this architecture allows models to dynamically focus on relevant portions of input data when generating outputs, mimicking in some ways how human cognition selectively attends to pertinent information (He et al., 2024). This architectural innovation solved fundamental limitations of previous recurrent neural network approaches, which struggled with long-range dependencies and computational efficiency. The attention layer enables Transformer-based models to capture complex relationships within data, making them exceptionally capable of understanding and generating human language. Research has demonstrated that not all attention components contribute equally to model performance, and ongoing work continues to refine these architectures for greater efficiency and reliability (He et al., 2024). These technical advances have directly enabled the development of large language models that can engage in sophisticated educational dialogues, generate explanatory content, and provide personalized feedback.

The practical manifestation of these architectural advances is evident in the emergence of powerful AI tools such as ChatGPT, Google Gemini, and similar systems that are rapidly being integrated into educational contexts. These tools represent the culmination of years of research in deep learning and natural language processing, combined with training on massive text corpora that include educational materials, academic publications, and instructional content. A comprehensive review of Transformer-based models highlights how systems like ChatGPT and Bard have achieved remarkable capabilities in text generation, question answering, and conversational interaction (Illangarathne et al., 2024). The educational implications of these capabilities are profound, as these systems can explain complex concepts, generate practice problems, provide feedback on student writing, and engage in Socratic dialogue to guide learning. The accessibility of these tools has democratized access to AI-assisted learning, allowing students and educators to leverage sophisticated language models without requiring technical expertise or computational resources. This accessibility is accelerating the integration of AI into educational practice at all levels, from primary education through postgraduate research.

The application of generative AI tools in higher education is already demonstrating significant potential for enhancing academic work. Research has explored how tools like Google Gemini can serve as research writing assistants, helping students and scholars navigate the complexities of academic writing, literature review, and manuscript preparation (Barrot, 2025). These applications extend beyond simple text generation to include brainstorming research questions, identifying gaps in literature, structuring arguments, and improving clarity and coherence in academic prose. The systematic integration of ChatGPT into educational processes has been examined through comprehensive literature reviews, revealing both the transformative potential and the implementation challenges associated with these technologies (Prananta et al., 2023). Educators are discovering that generative AI can serve as a tireless teaching assistant, capable of providing immediate responses to student queries, generating customized learning materials, and offering preliminary feedback that allows human

instructors to focus on higher-order pedagogical tasks. The capability of these systems to generate human-like text has also raised important questions about academic integrity, assessment validity, and the skills that students need to develop in an AI-augmented educational environment.

The impact of AI on teaching practices and teacher professional development represents a significant dimension of educational transformation. A systematic review of AI applications in teaching reveals that these technologies are reshaping how educators design instruction, assess learning, and manage classroom activities (Tan et al., 2025). AI-powered tools can analyze student performance data to identify learning gaps, recommend instructional interventions, and predict student outcomes, enabling teachers to make more informed pedagogical decisions. Professional development programs are increasingly incorporating AI literacy components to prepare educators for working alongside intelligent systems. The relationship between human teachers and AI tools is evolving toward a collaborative model in which AI handles routine tasks such as grading, scheduling, and basic query responses, while teachers focus on mentoring, motivation, and the interpersonal aspects of education that remain distinctly human. This redistribution of educational labor has implications for teacher roles, training requirements, and the professional identity of educators. Institutions that effectively prepare their faculty for this transition will be better positioned to harness AI capabilities while preserving the human elements that are essential to meaningful education.

The trajectory of AI development in education points toward increasingly sophisticated and capable systems that will expand the boundaries of what is possible in teaching and learning. A comprehensive systematic review of AI in education has identified persistent trends toward greater personalization, automation, and intelligence in educational technologies (Garzon et al., 2025). The benefits documented in the literature include enhanced learning outcomes, improved accessibility, increased efficiency, and expanded educational opportunities. However, these benefits are accompanied by challenges related to data privacy, algorithmic bias, digital equity, and the need for appropriate regulatory frameworks. The research community continues to grapple with questions about how to maximize the benefits of AI while mitigating potential harms. What is clear from the evidence is that AI capabilities will continue to advance, driven by ongoing improvements in algorithms, computing power, and data availability. Educational institutions that develop strategic approaches to AI integration today will be better prepared to navigate the more profound transformations that lie ahead.

The Chinese experience in implementing AI-assisted education provides valuable insights into the strategies and challenges associated with large-scale AI integration. Research examining the digital transition framework for higher education in China reveals systematic approaches to incorporating AI into engineering education and other disciplines (Zhang et al., 2025). The Chinese initiatives demonstrate the importance of national policy support, infrastructure investment, and coordinated implementation strategies for successful AI adoption in education. The challenges identified include faculty readiness, curriculum adaptation, and the need for ongoing technical support. These experiences offer lessons for institutions in other contexts that are developing their own AI integration strategies. The scale of AI adoption in Chinese higher education also provides evidence of the feasibility of widespread implementation, even as it highlights the resources and commitment required to achieve meaningful transformation. International comparative perspectives on AI in education reveal both common challenges and context-specific factors that shape implementation outcomes.

Speculative analysis of educational futures reveals both utopian and dystopian scenarios that may unfold as AI becomes more deeply embedded in education. Research exploring future scenarios envisioned by AI systems themselves, including ChatGPT, Gemini, and DeepSeek, provides thought-provoking perspectives on potential trajectories (Wong, 2025). Utopian scenarios envision AI enabling

truly personalized learning experiences that adapt to individual needs, democratizing access to high-quality education regardless of geographic or socioeconomic constraints, and freeing educators to focus on creativity, critical thinking, and human connection. Dystopian scenarios warn of algorithmic control over educational pathways, the erosion of human judgment in educational decisions, widening inequalities between those with access to advanced AI tools and those without, and the potential loss of human agency in learning processes. The actual future of AI in education will likely contain elements of both scenarios, shaped by the policy choices, institutional decisions, and social values that guide AI development and deployment. The responsibility for steering toward more beneficial outcomes rests with educators, policymakers, technologists, and society as a whole.

The convergence of expanding digital data, advancing AI architectures, and growing practical applications creates a clear trajectory of increasing AI presence in education. The Transformer architecture and attention mechanisms that power current AI systems represent significant advances over previous approaches, but they are themselves subject to ongoing refinement and eventual supersession by more capable architectures. Research continues to optimize attention mechanisms, improve computational efficiency, and enhance model capabilities (He et al., 2024). Future AI systems will likely exhibit greater reasoning abilities, improved factual accuracy, better alignment with educational objectives, and more sophisticated understanding of pedagogical principles. The feedback loop between AI deployment in education, data generation, and model improvement suggests that progress will accelerate rather than plateau. Educational institutions must prepare not only for current AI capabilities but for systems that will far exceed what is possible today. This preparation requires developing adaptive governance frameworks, cultivating AI literacy among all stakeholders, and maintaining focus on educational values even as technological capabilities expand.

The future of education in an AI-augmented world will be characterized by continuous change, requiring institutions to develop capabilities for ongoing adaptation. The evidence from current research and implementation experiences suggests that AI will become an indispensable component of educational infrastructure, comparable to how digital technologies themselves became essential over the past two decades. The question is not whether AI will transform education but how institutions will manage this transformation to serve educational purposes effectively. Success will depend on strategic vision, sustained investment, stakeholder engagement, and ethical frameworks that ensure AI serves human flourishing rather than replacing human judgment. Educational leaders must cultivate environments in which AI tools are viewed as powerful instruments that extend human capabilities rather than threats to be resisted or panaceas to be uncritically embraced. The path forward requires navigating between technological determinism and willful ignorance, embracing the genuine benefits that AI offers while remaining vigilant about potential harms and limitations. The institutions that master this balance will define the future of education in the AI era.

4. DISCUSSION

The digital transformation of higher education represents one of the most significant changes in the history of academic institutions. This paper has examined the key dimensions of this transformation, including the technologies driving change, the barriers impeding progress, and the strategies being employed to navigate this complex landscape. The evidence from the literature suggests that successful digital transformation requires a comprehensive approach that addresses technological, organizational, cultural, and policy dimensions simultaneously. Institutions that treat digital transformation as merely a technology project, without attending to the human and organizational factors involved, are

unlikely to achieve the benefits they seek. Conversely, institutions that develop clear strategic visions, build digital capabilities among faculty and staff, engage stakeholders effectively, and establish appropriate governance frameworks are well-positioned to thrive in an increasingly digital educational environment.

The review of recent research reveals both progress and persistent challenges in digital transformation efforts. On the positive side, there is growing awareness among higher education leaders of the importance of digital transformation, increasing investment in digital infrastructure and platforms, and accumulating experience with transformation strategies and practices. The COVID-19 pandemic, despite its devastating impacts, served as a catalyst that accelerated digital adoption and demonstrated that institutions can adapt quickly when circumstances demand. However, significant challenges remain, including inadequate digital infrastructure in many contexts, resistance to change among faculty and staff, concerns about educational quality and equity, and the need for clearer governance frameworks for digital education. Addressing these challenges will require sustained commitment from institutional leaders, policymakers, and other stakeholders over the coming years.

The integration of artificial intelligence into higher education governance and operations emerges as a particularly significant trend for the future. AI technologies have the potential to transform how institutions recruit and support students, deliver instruction, assess learning, and manage operations. Predictive analytics can help identify students at risk and enable proactive interventions. Intelligent tutoring systems can provide personalized learning experiences at scale. Automated processes can increase efficiency and allow human staff to focus on higher-value activities. However, the deployment of AI in education also raises important ethical questions about privacy, fairness, transparency, and accountability. Institutions must develop robust policies and practices to ensure that AI systems are used responsibly and that their benefits are distributed equitably across all student populations.

Looking to the future, several priorities emerge for higher education institutions seeking to advance their digital transformation journeys. First, institutions must continue to invest in digital infrastructure and platforms, ensuring that they have the technical foundation needed to support current and future educational activities. Second, developing digital competencies among faculty, staff, and students must remain a priority, as the human capacity to effectively use technology is as important as the technology itself. Third, institutions should establish clear governance frameworks for digital education that address issues such as data privacy, cybersecurity, academic integrity, and accessibility. Fourth, transformation efforts should be guided by educational values and focused on improving learning outcomes rather than pursuing technology for its own sake. Fifth, institutions must attend to issues of equity and inclusion, ensuring that digital transformation expands rather than restricts access to quality education.

The coming decade will likely see even more profound changes in how higher education institutions operate and deliver their missions. Emerging technologies such as extended reality, blockchain, and advanced AI systems promise to create new possibilities for immersive learning, secure credentialing, and intelligent institutional management. At the same time, societal expectations for education are evolving, with growing demands for lifelong learning, skills-based credentials, and flexible delivery models. Higher education institutions that embrace digital transformation strategically and thoughtfully will be best positioned to meet these evolving demands while fulfilling their enduring missions of knowledge creation, dissemination, and preservation. The research reviewed in this paper provides a foundation for understanding the current state of digital transformation in higher education and charting paths forward. Continued scholarship and practice in this area will be essential as institutions navigate the opportunities and challenges of the digital age.

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4. Explicating Barriers to Teacher's AI Literacy: A Critical Literature Review

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Abstract: Educational systems now more than ever require teachers to acquire AI literacy as artificial intelligence continues to integrate deeply into these systems. The analysis in this article reviews literature to identify significant obstacles that prevent the inclusion of AI literacy within teacher education and professional development programs. Using a thematic synthesis of recent peer-reviewed research, policy papers, and international frameworks, five interrelated categories of barriers are identified: The implementation of AI literacy in teacher education faces barriers from policy and institutional gaps alongside technological and infrastructural limitations which are compounded by insufficient teacher preparedness and training together with affective and cultural resistance and unaddressed ethical and socio-technical concerns. The research demonstrates how these challenges form a systemic network and advocates for a comprehensive educational model that focuses on teachers while integrating both cognitive skills and ethical judgment for AI literacy. The paper presents guidance for curriculum developers, policymakers and teacher educators while proposing future research directions for evidence-based deployment of AI literacy frameworks in educational settings.

Keywords: AI literacy, teacher education, artificial intelligence in education, ethical reasoning, professional development, implementation barriers.

1. INTRODUCTION

The increasing presence of artificial intelligence (AI) within societal frameworks presents fresh educational challenges and opportunities. With AI technologies becoming central to teaching methods and educational management systems educators need to establish core AI knowledge known as AI literacy (Ng et al., 2021; Zhang & Aslan, 2021). AI literacy requires knowledge of AI operations along with critical application analysis and ethical assessments to modify teaching methods (Sands et al., 2020). Teachers in the 21st century now require AI literacy as a fundamental skill to promote the ethical and knowledgeable use of technology in educational environments (Younis et al., 2023).

Research demonstrates that despite increasing scholarly and policy focus on AI education teacher professional development programs still exhibit inconsistent and fragmented AI literacy integration (Holmes et al., 2022; Popenici & Kerr, 2017). Though several proposals exist for frameworks to measure AI literacy (Younis et al., 2023), numerous obstacles prevent schools from implementing these tools. The obstacles for implementing AI literacy at schools consist of limited institutional support and inadequate training opportunities, technological infrastructure gaps as well as the absence of ethical and pedagogical guidance about AI usage in educational settings (Luckin, 2021; Zawacki-Richter et al., 2019). Teachers frequently show doubt and questioning toward AI systems while they struggle to comprehend how AI makes decisions and measure its effects on students according to Tsai et al. (2023).

The existing conversation on AI literacy prioritizes technical skills but overlooks socio-ethical considerations and classroom application effects (Jobin et al., 2019; Dignum, 2021). Many educators currently lack the skills required for critical evaluation of algorithmic bias, data privacy issues, surveillance concerns, and the automation of teaching activities. The introduction of AI tools into secondary education environments lacks clear pedagogical or ethical guidelines to ensure proper usage.

Because of these challenges it becomes imperative to pinpoint and examine the various obstacles that stand in the way of teaching AI literacy to educators. Educators must understand these barriers before they can create training programs and policy interventions that support meaningful engagement with AI in teaching environments. The article seeks to combine recent research findings about the problems teachers encounter when learning and implementing AI literacy. The research identifies different barriers through critical analysis which leads to enhanced theoretical insights into systemic and educational obstacles that prevent AI from reaching its full educational potential.

2. METHODOLOGICAL APPROACH

The study uses a bibliographic and theoretical research design to critically analyze and consolidate existing knowledge about teacher literacy barriers regarding AI. The research does not depend on empirical data collection but instead bases its findings on a structured analysis of recent peer-reviewed academic literature alongside policy reports and theoretical models developed in the last 5 to 10 years. This time frame selection seeks to gather recent discussions in AI educational integration alongside corresponding conceptual advancements and policy reactions while focusing on teacher skills development.

The chosen sources focused on four main aspects of AI literacy which included technical knowledge and understanding, pedagogical application methods, ethical analysis, and the support from educational institutions. The research analyzed literature from major academic databases including Scopus, Web of Science, and ERIC using terms like “AI literacy,” “teacher education,” “artificial intelligence in education,” “barriers,” “professional development,” and “ethical challenges in AI” and it also covered relevant white papers and frameworks from UNESCO, OECD, and the European Commission which influence global discussions about digital and AI competencies for educators.

The article uses thematic synthesis to analyze the literature which enables researchers to detect and systematize repeated patterns along with conceptual voids and structural barriers identified in the research area. The thematic synthesis method proves ideal for theoretical reviews because it enables researchers to organize qualitative data into developing themes while maintaining both their complexity and their diversity of viewpoints (Thomas & Harden, 2008). The analytical process involved three stages: The analysis began with coding barriers and challenges from each source followed by organizing these codes into main themes like infrastructural limitations and ethical unpreparedness and concluded with an evaluation of these themes against existing teacher AI literacy frameworks.

The strategy provides a comprehensive understanding of the various factors that influence teachers’ interaction with AI technologies. This approach reveals unexplored issues such as insufficient ethical training and dominant technocentric views while providing fresh perspectives for academic research and policymaking. The article uses this bibliographic and thematic framework to achieve two goals: summarizing current knowledge and developing new research directions and practical insights.

2.1 Literature-Based Findings / Thematic Analysis

The analysis of contemporary academic and policy publications shows multiple systemic, pedagogical and conceptual obstacles to incorporating AI literacy into teacher education programs. The barriers to AI literacy adoption in teacher education extend beyond technology and are firmly established within institutional frameworks along with professional development approaches and ethical issues. This section examines and combines essential themes from peer-reviewed studies and international frameworks over the last ten years to characterize the present situation of AI literacy instruction for educators. The following thematic analysis identifies critical barriers that need resolution for effective and ethical AI integration into educational settings.

2.2 Policy and Institutional Barriers

The advancement of AI literacy among educators faces significant challenges due to missing national or institutional guidelines which should define AI competencies and support professional development. Even though there is rising global advocacy for digital and AI competencies in education systems worldwide, numerous countries do not have practical guidelines that turn policy statements into concrete teacher development plans (Holmes et al., 2022; UNESCO, 2021). The lack of uniform national or institutional AI frameworks results in fragmented AI literacy comprehension and application across schools.

UNESCO's 2021 global framework for AI education emphasizes the importance of equal access to both AI tools and teaching resources. The integration of these strategies into secondary education systems has faced inconsistent application and adaptation across different contexts. National education strategies focus on large-scale digital transformation yet do not specify the teaching competencies needed for teachers to use AI effectively according to OECD (2021). Educators experience uncertainty because macro-level educational policies do not match micro-level classroom practices and they lack adequate institutional support to handle new technologies (Zawacki-Richter et al., 2019).

Educational technology policies prioritize innovation and digital preparation yet they overlook teaching methods and ethical considerations of AI deployment which prevents educators from receiving essential decision-making frameworks (Luckin, 2021; Popenici & Kerr, 2017). This policy-practice gap both weakens AI literacy programs and creates teacher resistance or passive acceptance instead of leading to active reflection and use of AI tools (Tsai et al., 2023).

The process of implementing AI-focused teacher development initiatives faces delays or reduced impact because of financial constraints alongside bureaucratic delays and conflicting curriculum objectives (Eickelmann & Gerick, 2020). Teachers report that national policy-driven training programs remain either too broad or focused on technological theories which do not connect to their teaching environments (Zhang & Aslan, 2021).

The existing research indicates that institutional inertia combined with fragmented policy design and insufficient resource distribution creates a significant structural obstacle to building comprehensive AI literacy among educators. To overcome this barrier we need both national guidelines and teacher-focused policies that adapt to local needs and align educational innovation with daily teaching practices.

2.3 Technological and Infrastructural Barriers

The uneven distribution of technological infrastructure and AI tools presents a major challenge for adopting AI literacy in schools. The deployment of AI in educational institutions remains inconsistent

despite extensive promotion of its potential benefits. Educational institutions situated in rural regions or operating with limited budgets do not possess sufficient hardware, internet access, or software needed to enable meaningful educator interaction with AI technologies (Zawacki-Richter et al., 2019; OECD, 2021). The gap between educational resources creates a digital divide that restricts professional development opportunities for teachers and decreases their access to AI educational tools.

The systematic review by Zawacki-Richter et al. (2019) on AI applications in higher education pointed out that accessibility problems extend beyond universities and represent a widespread pattern throughout all educational sectors. The implementation of AI tools in secondary schools becomes impractical or unsustainable due to outdated equipment alongside incompatible digital systems and inadequate IT support (Luckin, 2021). Infrastructure constraints create obstacles for teachers that can lead to their frustration and block AI concept integration into educational programs.

A lack of strategic investment in long-term technological development at schools impedes both the sustainability and scalability of AI projects (Eickelmann & Gerick, 2020). The availability of AI platforms does not ensure accessibility for educators who might struggle with complex technical requirements and lack both language support and proper training (Zhang & Aslan, 2021). Teachers generally use digital tools passively or opt to stay away from them because they view AI technology as an unnecessary complication rather than a valuable educational resource.

The situation worsens because AI technologies advance very quickly which makes it difficult for school systems to keep up. Efforts to create AI literacy programs will fail to connect with classroom practice without strong IT infrastructure and ongoing technical support. To overcome these challenges educational institutions need to establish technological ecosystems that provide equal access and support while responding to local educational needs and teaching objectives.

Teacher Preparedness and Professional Development

Educators face major obstacles toward attaining AI literacy because they receive insufficient pre-service and in-service training programs. Although conversations about preparing teachers for AI-enabled classrooms are expanding, research shows that educators generally encounter AI principles only briefly during their standard teacher training programs. Many educators begin their careers without understanding the essential knowledge and teaching methods needed to work with AI technologies (Sands et al., 2020; Younis et al., 2023).

Younis et al. According to Younis et al. (2023), teacher education programs prioritize general digital literacy while neglecting specialized skills for understanding AI systems and algorithmic principles as well as data ethics. The training gap continues to exist throughout professional development because educators have access only to optional or broken programs which focus too much on technical details instead of teaching methods that match teachers' actual classroom needs. Educators often experience feelings of being unprepared alongside apprehension when they attempt to use AI in their teaching methods.

The problem intensifies because there are no established pedagogical frameworks that focus on AI. Educators must create their own implementation strategies because no instructional models demonstrate meaningful AI integration in various subjects and learning activities (Zawacki-Richter et al., 2019; Holmes et al., 2022). The absence of clear guidance results in inconsistent educational application of AI and supports its perception as an experimental tool instead of a transformative educational asset.

Teacher agency suffers from the gap between technological advances and practical implementation. Educators commonly express feelings of exclusion from institutional decision-making about AI deployment which restricts their professional independence and decreases their involvement with the

technology (UNESCO, 2021; Zhang & Aslan, 2021). Educators who do not participate in creating or choosing AI tools experience a reduction in both their preparedness and motivation to use these technologies.

Research experts call for a transformed approach to teacher professional development which combines AI literacy with fundamental teaching methods while emphasizing ethical understanding and reflective practice (Luckin, 2021; Tsai et al., 2023). AI literacy implementation will stay fragmented and hard to reach for its intended audience unless structural changes occur.

Affective and Cultural Barriers

Teachers face substantial barriers to AI literacy implementation due to affective and cultural factors besides structural and pedagogical obstacles. Educators worry that AI development may lead to their replacement or diminish their professional influence and control over educational decisions (Luckin, 2021). The concerns of educators regarding AI systems are justified because the swift development of AI tools for grading and personalized learning tasks creates doubts about the continued relevance of teachers in AI-integrated educational environments.

Educators exhibit significant resistance to adopting new technology because they lack confidence or have had negative experiences with educational tools before. Ng et al. (2021) assert that teachers' hesitation to participate in AI training and classroom applications stems largely from their low self-efficacy regarding emerging technologies such as AI. The psychological barrier becomes more evident among teachers who have minimal experience with digital tools and computational thinking.

Teachers' methods for teaching AI literacy are influenced by cultural views regarding artificial intelligence. Within numerous situations AI remains a highly technical or abstract field perceived to be unrelated to day-to-day educational issues. The way AI is presented creates a barrier that leads teachers to view AI as irrelevant and inaccessible which results in passive behavior and withdrawal (Zawacki-Richter et al., 2019). Teachers may experience social or professional discouragement in adopting new AI-based practices due to school cultures that fail to support innovation and digital experimentation while fearing judgment or institutional pushback (Zhang & Aslan, 2021).

Understanding AI literacy requires professional development programs to focus on teachers' emotions and their personal beliefs and identities. As Luckin (2021) and Holmes et al. (2022) demonstrated that teachers must receive technical training alongside supportive leadership and community building to transform educational culture and embrace their roles in digital education advancements.

2.4 Ethical and Socio-Technical Barriers

The integration of artificial intelligence within educational systems leads to critical ethical and socio-technical challenges which serve as major obstacles to teacher involvement and literacy development. Educators lack sufficient understanding of the ethical concerns tied to AI application in teaching environments. Jobin et al. (2019) reveals through their global landscape analysis of AI principles that educators and other practitioners find no consistent and accessible guidance to help them resolve ethical issues including algorithmic bias and the hidden processes of AI decision-making. Educators face a lack of preparation to identify and deal with ethical outcomes when they use AI technology in their classrooms.

Teachers face additional challenges due to their lack of clarity on essential socio-technical matters that include data privacy issues and both fairness and algorithmic bias concepts. Educators express a lack of knowledge about student data handling by AI platforms and confusion over responsibility

for AI-generated harmful outcomes (Holmes et al., 2022; Tsai et al., 2023). Teachers without proper training risk unintentionally supporting discriminatory behaviors and may overlook when AI systems sustain existing biases.

The complexity of AI ethics stems from its cross-disciplinary nature which involves law, sociology, philosophy and computer science making ethical decision-making difficult for educators who lack specialization (Popenici & Kerr, 2017). Educators take the lead in AI technology deployment without essential frameworks or institutional backing to critically engage with these technological systems. This situation leads educators to either completely avoid AI utilization or only achieve a basic awareness of its functions and constraints which prevents both responsible practice and innovative development.

The current obstacles demonstrate a critical requirement for teacher education programs to embed ethical reasoning and socio-technical literacy as fundamental elements of AI literacy training. Teachers must develop ethical discernment beyond technical competence to contribute effectively to fair and equitable AI applications in education.

3. DISCUSSION

Multiple interconnected problems create a complex network of challenges that prevent educators from successfully implementing AI literacy. Research points to separate challenges like poor infrastructure and ethical uncertainties as obstacles yet their combined impact becomes more severe due to their inter-related nature in educational contexts (Holmes et al., 2022; Ng et al., 2021; UNESCO, 2021).

The lack of national educational frameworks for AI literacy creates confusion about curriculum design and prevents strategic coordination across teacher education programs (UNESCO, 2021). Teacher preparation programs face challenges in implementing AI meaningfully due to undefined competencies and absent policy directives which leads to disjointed professional development approaches (Sands et al., 2020; Younis et al., 2023). Educators enter teaching environments lacking basic AI knowledge which prevents them from applying AI techniques in teaching and ethical decision-making.

The absence of clear policy interacts with existing technological and infrastructural barriers. Schools located in marginalized or underfunded areas experience greater negative impact from unequal access to digital resources and technical assistance (Zawacki-Richter et al., 2019). Teachers in advanced technological environments often face platform integration challenges and system reliability issues which prevent effective AI tool experimentation and integration (Luckin, 2021). These limitations restrict learning possibilities while generating the belief that AI remains out of reach and irrelevant for daily teaching practices.

Implementation becomes more difficult because affective and cultural barriers create additional challenges. Many teachers fear that AI will undermine their independence and replace important parts of their professional roles as outlined by Luckin in 2021. Teacher apprehension grows stronger due to low self-confidence and resistance toward change which becomes more evident when new innovations lack adequate training or demonstrable pedagogical advantages (Ng et al., 2021). These psychological and cultural barriers decrease teacher interest in using AI technologies despite their technical availability.

The ethical and socio-technical challenges represent both highly significant and frequently neglected barriers. Studies show that teachers maintain limited understanding regarding AI ethical matters which involve algorithmic bias and privacy issues alongside fairness concerns (Jobin et al., 2019; Tsai et al., 2023). Modern teacher education and professional development frameworks lack appropriate

tools for ethical reasoning to address these concerns (Zhang & Aslan, 2021). Educators demonstrate technical skills yet lack the moral decision-making abilities needed to effectively implement AI tools in educational settings.

These barriers function collectively rather than independently. The lack of national policy frameworks generates training deficiencies that produce teacher uncertainty and diminished confidence which leads to stronger resistance against AI integration (Holmes et al., 2022; Sands et al., 2020). The existence of technological constraints stops practical AI application while simultaneously strengthening negative emotional beliefs about AI's complexity and trustworthiness (Luckin, 2021). Educators might choose not to incorporate AI in their teaching practices due to ethical doubts even when they have access to necessary infrastructure and training methods.

The connection between these factors demands a comprehensive systemic method to teach AI literacy within educational systems. Competency goals in national and institutional policies require the establishment of infrastructure availability along with ethical training and pedagogically robust AI models (UNESCO 2021; Popenici & Kerr 2017). Educators require professional development programs that extend beyond technical skill training to include critical thinking abilities and ethical understanding as well as cultural preparedness which develop the reflective capabilities necessary for responsible AI engagement (Zawacki-Richter et al., 2019; Tsai et al., 2023).

The research shows that to eliminate obstacles to AI literacy we need combined approaches that tackle policy alignment together with technological equity as well as emotional and cultural acceptance and ethical preparedness. The educational system needs a comprehensive approach to provide teachers with the necessary tools and confidence to integrate AI into educational practices responsibly.

3.1 Multi-Level Change for AI Literacy Implementation

A systemic and multi-level transformation involving coordinated changes throughout policy, infrastructure, pedagogy and educator beliefs is necessary for effectively integrating AI literacy into educational systems. The escalation of artificial intelligence in educational settings faces challenges as fragmented efforts persist because comprehensive strategies to unify interdependent layers are missing.

The absence of national AI literacy frameworks at the policy level has resulted in varied expectations among schools and teacher training institutions. As UNESCO (2021) and Holmes et al. Holmes et al. (2022) emphasize the importance of policy directives to define educational AI competencies since they facilitate systematic curriculum development and resource allocation. AI literacy implementation efforts without mandated policy guidelines typically stay limited to pilot programs or rely on local leadership which results in inconsistent outcomes and unequal access.

It is critical to establish both technological capabilities and infrastructure adequacy at the same time. Educators need access to both technology and dependable internet connections as well as institutional backing to integrate AI tools into their everyday teaching routines. Zawacki-Richter et al. Zawacki-Richter et al. (2019) reported that digital innovation faces barriers to equitable participation because schools experience an unequal distribution of technological resources. AI platforms by themselves fall short of achieving meaningful adoption when teachers lack understanding of their educational benefits.

Pedagogical innovation is also essential. Educational systems today do not provide sufficient frameworks to integrate AI literacy with instructional and ethical objectives. Sands et al. According to research by Sands et al. (2020) and Zhang and Aslan (2021), AI tools should be embedded in educational approaches that prioritize constructivist and learner-centered teaching with a strong focus on

inquiry-based learning and critical thinking instead of functioning as simple content-neutral technologies. Educators must urgently adopt teaching models that enable the meaningful integration of AI into their instructional practices.

Professional identity and teacher mindset significantly determine their role. The way teachers perceive AI—including apprehensions about job loss, questions about its educational benefits, and their ability to use AI tools—strongly influences how AI is implemented in educational settings (Luckin, 2021; Ng et al., 2021). Teachers struggle to accept AI because ethical questions about student data privacy and algorithmic bias make them uncomfortable. AI education requires professional development that extends past technical abilities to foster thoughtful interactions with its ethical, social, and educational effects (Tsai et al., 2023).

The four dimensions—policy, infrastructure, pedagogy, and teacher mindset—function as interconnected systems which support and strengthen one another. Infrastructure without pedagogy leads to underutilization and pedagogy without teacher buy-in proves ineffective. The development of AI literacy in education demands an integrated approach that unites multiple aspects of the educational system. The approach demands educators receive both resources and clear guidance along with ethical frameworks while top-down strategies integrate with bottom-up engagement to enable responsible AI navigation in teaching practices.

3.2 Extending Current Understandings and Addressing Conceptual Gaps

The research synthesis presented here adds to educational studies on AI literacy by analyzing multiple implementation obstacles faced by teachers in a comprehensive manner. Research confirms the importance of AI literacy in teacher education (Ng et al., 2021; Younis et al., 2023), but many studies examine this topic separately by centering on either technological readiness, pedagogical adaptation, or ethical awareness. The article shows how institutional, infrastructural pedagogical affective and ethical barriers demonstrate domain interdependence which uncovers systemic misalignment not fully explored in previous studies.

The evolution of current debates now includes a clear linkage among policy development and training programs with ethical thinking processes. Researchers have examined ethical considerations in AI (Jobin et al., 2019; Holmes et al., 2022) yet these studies seldom connect these issues to the structural and pedagogical difficulties teachers encounter in practical environments. This research connects the existing research gap by showing that a lack of ethical training and institutional support together weakens teacher agency and confidence. The addition of ethical considerations into AI literacy implementation frameworks extends previous models which focused mainly on technical aspects (Zawacki-Richter et al., 2019).

UNESCO (2021) as well as Holmes et al. (2022) advocated for national AI education strategies. This article highlights the practical disconnect between innovation policy and classroom practice while emphasizing that research has yet to thoroughly examine the tension between national AI education strategies and empirical findings. The synthesis demonstrates that educators at the foundational level find top-down policy mandates ineffective because professional development programs are neither adequate nor specialized enough (Sands et al., 2020).

The study delivers a meaningful impact by examining how teachers' emotional responses and cultural backgrounds contribute to their resistance. Research by scholars such as Luckin (2021) along with Ng et al. (2021) has examined fear and skepticism but tends to treat these issues as secondary or individual-level concerns. Research by Luckin (2021) and Ng et al. (2021) explored fear and skepticism among teachers yet these elements continue to be seen as secondary issues at the individual

level. The analysis transforms these concerns into systemic obstacles connected to institutional practices and the absence of support together with dominant narratives about automation and teacher job replacement. The perspective changes from blaming teachers for reluctance to exploring structural enablers and constraints.

This article addresses a gap in existing research by developing a coherent analytical framework from studies in educational technology, ethics, professional development, and policy studies. A cross-disciplinary synthesis delivers a multifaceted perspective on AI literacy which demands synchronized interventions at different levels.

Effective AI literacy strategies should focus on teacher-centered approaches that integrate both cognitive understanding and ethical considerations. Research shows that effective AI literacy frameworks must combine technical strength with practical insights from educators' professional experiences and ethical teaching duties. Most current strategies to teach AI literacy follow a hierarchical or technology-focused framework which prioritizes computational skills and tool mastery (Ng et al., 2021; Younis et al., 2023). Technical skills continue to matter but fail to address the complex issues teachers encounter when applying AI in their teaching methods.

The research presents the essential nature of teacher-centered approaches which match educators' cognitive processes as well as their pedagogical decisions alongside ethical considerations. The cognitive dimension refers to educators' comprehension of AI system functionality alongside its potential effects on instructional design and student learning processes. The ethical dimension requires educators to examine fairness and accountability while also assessing transparency and the wider societal impacts of integrating AI into educational systems as mentioned by Jobin et al., 2019 and Holmes et al., 2022. The current frameworks fail to provide sufficient support for teachers to effectively connect the cognitive and ethical dimensions of AI in education through practical and contextually significant methods.

Recent academic studies advocate for developing ethical reasoning abilities among teachers and incorporating them into educational planning because of the risks associated with algorithmic bias and data privacy which could reduce human decision-making power in education (Tsai et al., 2023; Luckin, 2021). Teachers frequently report a lack of preparation to manage ethical challenges because their professional development concentrates on functional skills instead of critical reflection (Sands et al., 2020). Educational AI literacy programs need to progress past simple knowledge acquisition to develop reflective practitioners who can handle complex ethical challenges.

This paper proposes building AI literacy programs that merge cognitive comprehension with ethical reasoning while integrating these elements into teacher education and institutional policy-making. Through this approach educators would gain both technical proficiency in AI tools and the ability to assess their impacts as well as minimize adverse effects while creating fair educational settings. Adopting multidimensional literacy stands as an essential step for guaranteeing that AI implementation in education supports human-centered teaching approaches.

4. CONCLUSION

AI literacy is essential for educators to prepare students for a digital society, fostering digital skills and ethical understanding (Ng et al., 2021; Holmes et al., 2022). However, its implementation in teacher training faces five key interconnected obstacles. Policy and institutional barriers stem from a lack of comprehensive national frameworks and innovation agendas conflicting with classroom realities (UNESCO, 2021; Holmes et al., 2022). Technological barriers involve exacerbated digital divides and outdated infrastructure limiting AI access. Teacher preparedness suffers from inadequate pre- and in-service training and a shortage of AI integration models (Sands et al., 2020; Younis et al.,

2023). Affective and cultural elements, like fear, resistance, and low confidence, also hinder teachers' AI interaction (Luckin, 2021; Ng et al., 2021). Furthermore, ethical and socio-technical issues, such as data privacy and algorithmic transparency, are insufficiently explored in teacher education, leaving educators unprepared for moral challenges (Jobin et al., 2019; Tsai et al., 2023).

Overcoming these barriers requires comprehensive, multi-level interventions addressing technology, pedagogy, and ethics through a unified strategy and teacher support. Effective AI literacy integration demands coordinated action from multi-tiered stakeholders. Curriculum developers must embed age-appropriate AI literacy, covering cognitive and ethical aspects, within national and local educational systems (Holmes et al., 2022; UNESCO, 2021). Frameworks need to account for diverse digital access, professional capacities, and student populations. Political leaders must integrate AI literacy into digital transformation strategies, providing dedicated funding and ensuring fair access (Luckin 2021; Zawacki-Richter et al. 2019). Ethical governance requires policy consideration for teacher autonomy, data protection, and algorithmic fairness (Jobin et al., 2019; Tsai et al., 2023). Teacher educators are crucial for addressing pedagogical and affective obstacles, with training programs encompassing technical skills, ethical reflection, and critical AI tool interaction (Ng et al., 2021; Younis et al., 2023). Professional development should expand beyond tool-based skills to robust pedagogical frameworks for AI-influenced learning.

While existing literature highlights these barriers, empirical studies are needed to confirm theoretical findings. Researchers should conduct large-scale studies to explore context-specific barriers and the influence of teacher backgrounds, beliefs, and school cultures on AI engagement. New assessment tools are required to validate ethical and pedagogical AI literacy, moving beyond technical skills (Sands et al., 2020; Younis et al., 2023). Longitudinal and comparative research can reveal the impact of training and policy changes on teacher preparedness. This future research will facilitate a practical understanding of educator preparation for effective, ethical, and socially responsible AI usage.

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5. Codocencia. Una posible coexistencia de lo presencial y lo virtual

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Abstract: Thinking in terms of co-teaching in the 21st century may give the impression of taking us back to times gone by. To a large extent, co-teaching is perhaps not in vogue, but we consider it, and it has not ceased to be, an ideal way of working in the classroom. It is an inclusive approach that considers the people who come together in the classroom, facilitating the teaching-learning process, collaborative work and teaching culture. With the advent of new technologies (such as Artificial Intelligence), co-teaching is evolving and becoming more contemporary. This technological development should not detract from the meaning of co-teaching, but rather endow it with new responsibilities. In this sense, this chapter is approached as a work of theoretical reflection with the intention of sharing possible paths, providing an understanding of co-teaching and addressing its coexistence with Artificial Intelligence.

Keywords: Co-teaching, Artificial Intelligence, teaching

1. INTRODUCCIÓN

Lo más sencillo pueda que sea definir el concepto pedagógico de la codocencia como la coexistencia en el seno del aula de varios docentes, complementándose en el mejor de los casos y, por ende, brindando al alumnado la posibilidad de conocer de forma contrastada, de modo activo, así como participando de un discurso compartido. Igualmente, se podría limitar a una mera estrategia didáctica en la cual varios docentes intervienen del hecho educativo ante un grupo de estudiantes. A lo que se podría aunar la definición precisa ofrecida por Oller et al., (2018) como un modelo de docencia compartida en el aula; simultaneada y correspondida.

Se podría pensar que los discentes estén de forma presencial junto al codocente, o bien, ¿se ha parado a pensar en la posibilidad de un profesorado on line o asistido por la Inteligencia Artificial (en adelante IA)? Con todo, se suscribe la idea de una educación a distancia, pero no distante; lo que Carrasco y Baldivieso (2016) llamaron la educación a distancia sin distancia. Por ello, cabría reconsiderar a las tecnologías de la información y la comunicación (TIC) por aquella cualificada de tecnología de la relación, la información y la comunicación (TRIC). Un paso al frente donde la relación se erige como referente y sinónimo de participación y diálogo (Marta y Gambelas, 2023); tornando la “R” como una posibilidad para *apre(he)nder* del conocimiento.

La codocencia, según la literatura científica también llamada coenseñanza (en inglés co-teaching), se torna en un acto de cocreación promoviendo metodologías activas inspiradas en la colaboración entre docentes (Beamish et al., 2006; Waldron y Mcleskey, 2010; Pérez et al., 2022); pudiéndose establecer en todos los ámbitos educativos, incluso en el universitario (Bekerman y Dankner, 2010). Aquí se aleja de la perspectiva *unicista* del enseñante de apoyo. Y adquiere desarrollo la codocencia desde el momento en que se impulsa la coordinación y secuenciación para enriquecer el proceso de enseñanza-aprendizaje y favorecer la cultura del aula colaborativa e inclusiva (Gutiérrez, 2020).

Nos posesionamos ante una acción educativa donde se engrandece el acto didáctico, más allá de una mera representación teatral y más cercano a una propuesta de convertir la didáctica en el arte de enseñar todo a todos, respetándose sus ritmos y características, sus condiciones o, también, sus dificultades. En este sentido, la codocencia impulsa el beneficio del grupo-clase, inspirándose en la frase de Comenio (2011, p 65) “hay que enseñar todo a todos”. Se torna en una valiosa experiencia educativa, donde educar sea lo que vale para la vida; en gran medida, para el desarrollo integral de las personas. Y, con ello, estamos ante un acicate para tornar el aula no solo en un espacio de confrontación de enseñanzas que incentiven diversos enfoques y explicaciones, sino un entorno que facilite la adquisición de los contenidos y aprendizajes (Rodríguez, 2014).

Visualizamos un contexto de aprendizaje multipersonal, además de colaborativo (Vangrieken et al., 2015) y, a la vez, una posibilidad de crecer no solo en el espíritu crítico (sinónimo de calificador o inclinado a enjuiciar) sino, también, en la criticidad. Es decir, cuando la criticidad se erige como la capacidad de tener o desarrollar criterios para... debatir o convencer, para refutar o requerir lucidez en el proceso de enseñanza-aprendizaje.

Introducir no es una tarea fácil, pero abre el camino para lo que vendrá después: el desarrollo de los contenidos en pro de dar a comprender la codocencia en lo presencial o lo virtual. Introducir como verbo transitivo cuenta con acepciones como conducir u orientar. Para ello, se ha redactado este preliminar al concepto de la codocencia.

Una introducción para dar a conocer y poder invitar a la lectura del presente capítulo. Que con el título genérico de: Codocencia. Una posible coexistencia de lo presencial a lo virtual; lo que se pretende es conocer y valorarla, en el marco de un trabajo de reflexión teórica, atendiendo al sentido que adquiere la coexistencia docente, o bien con las pantallas.

2. UNA REALIDAD QUE SE DECLINA

No es realmente un ejercicio de declinación gramatical, para obtener posibles flexiones casuales de una palabra. Se trata de establecer un terreno abonado para hablar de estrategias, de trabajo colaborativo y dar respuesta a la diversidad, a la atención personalizada y a la inclusión educativa. Por ello, para favorecer una docencia de calidad se ha de establecer que para “que sus enseñanzas sean de calidad ellos mismos tienen que estar cualificados” (Agudo, 2019). Y será cuando entra en juego la presencia de diferentes modelos de codocencia para dar respuesta a las personas implicadas.

Este concepto mantiene el propósito de ofrecer calidad al proceso. En este sentido, como algo esclarecedor nos inclinamos por la taxonomía de Villa et al. (2008) donde se establece una organización inspirada en la labor de enseñar según el hecho de:

Observar.- Un docente imparte el contenido de manera íntegra, mantiene el liderazgo transmisor de la materia, mientras que otro asume el papel de registrar cualquier tipo de incidencia académica o en lo concerniente a los comportamientos del alumnado.

Apoyar.- Un docente conduce la clase e imprime el ritmo de aprendizaje, de modo que el otro deambula entre el alumnado ayudando e, incluso, reconduciendo algunos comportamientos y orientando o apoyando sus quehaceres.

Paralelar.- El aula queda subdividida en, al menos, dos grupos y el profesorado imparte sus enseñanzas de forma paralela; estableciéndose situaciones de semejanza o equivalencia educativa.

Simultanear.- Fiel al significado de poder realizarse dos o más acciones a la vez, cada profesorado ha dividido previamente en grupos la clase y la enseñanza se lleva a cabo de forma coincidente.

Rotar.- Cada docente se establece en un grupo concreto y, en vez de, dar vueltas alrededor de un

eje, se produce unos movimientos de traslación sobre los diferentes grupos de estudiantes; pero en determinado momento un grupo trabaja sin la presencia de un profesor. Aunque esto puede ser esporádico.

Estacionar.- Se produce una división del alumnado y recursos según estaciones que se organizan de manera simultánea y son los propios estudiantes los que rotan por las estaciones y es en una de las estaciones en la que pueden trabajar sin la presencia del docente.

Alternar.- Sería un modelo de acción alternativa, pues un docente trabaja con un pequeño grupo enriqueciendo el proceso; ahora bien, el otro docente queda frente al gran grupo clase.

Complementar.- Se presentan acciones que persiguen mejorar lo que el otro docente está haciendo en la clase. Un ejercicio donde cada uno cumple su rol y entre ambos se complementan.

Equipar.- La simultaneidad se establece en la clase, donde un docente imparte contenidos y el otro, por ejemplo, apoya la acción del primero. Un ejercicio para planificar y enseñar, o bien evaluar asumiendo la responsabilidad con los estudiantes.

Un enfoque pedagógico y didáctico que incentiva la colaboración, la inclusión y, en la medida que sea posible, el apoyo individualizado, siendo un instrumento de atención a las necesidades de los estudiantes del aula (Durán y Miquel, 2019). Se está ante una encrucijada común con visos de mejorar los resultados de aprendizaje, comportamientos o la experiencia educativa.

3. Y, ¿TAMBIÉN CON LA TECNOLOGÍA?

Quizás se preste a confusión, a priori, introducir el concepto tecnología una vez hemos “declinado” la palabra codocencia. Cabría entenderlo como una partícula aclaratoria, a modo de punto y seguido, y nunca como un punto aparte. La tradición se centra en considerar que la verdadera educación se realiza entre personas. Tal como lo planteó Rousseau como un resultado con su lacónico “el hombre que vosotros habéis formado” (1981, p. 91). E, igualmente, bajo el prisma donde prevalece la que se realiza de corazón a corazón; en clara alusión a Howard G. Hendricks. Con todo y en referencia a Paulo Freire, la docencia necesita de técnicas y principios donde arraigarse pero, también, de una dosis de utopía (para alejarse de la quimera). A lo que cabría aunar el pensamiento amable y positivo, centrado en la elegancia y en la comprensión.

En este contexto, la tecnología no irá a eclipsar al docente del proceso de enseñanza-aprendizaje. En la aventura del saber en la sociedad postdigital (Gil, 2023) se podría buscar un fiel colaborador. Una especie de asistente en continua construcción que auxilia en la labor a desempeñar. No entrando en confrontación con el liderazgo del docente (o los docentes), el discurso emergente se centra en las posibilidades que se derivan de la alternativa a la estimada ayuda o capacidad de profundizar en el conocimiento. Del mismo modo que, se puede establecer de forma paralela visualizándolo como una lección aclaratoria (en diferentes formatos) al contenido que se está presentando. Así como, valorar la usabilidad como recurso facilitador y eficaz que se presenta a través de las TRIC.

En gran medida, estamos pensando en la IA como agente de razonamiento, de acción y de mejora a través de la planificación y colaboración (Román et al., 2025). Con ello, se potenciaría una manera de trabajo eficaz inspirada en una comunicación fluida y dando respuestas certeras con inmediatez; con una pretendida humanización del proceso bajo la intención de facilitar el entendimiento (Amar et al., 2026), pues la verdadera toma de decisión es del docente/docentes.

Y en este contexto de inspiración tecnológica el docente actúa, junto al asistente tecnológico, para que el acto didáctico sea un ejercicio facilitador del aprendizaje. La intención es tornarlo eficaz en cuanto a las tareas y como un ejercicio de aprendizaje en positivo, a la vez que atractivo e intuitivo,

posibilitando la eliminación de probables fricciones que se conviertan en obstáculos. Lo pretendido es anticiparse a las necesidades demandas por el alumnado. Y sin olvidarnos de un docente orientador capaz de enseñar con las herramientas que les corresponden a los estudiantes del segundo tercio del siglo XXI, donde se incluye a la IA (Pérez, 2025).

Una tecnología que se expresa en tiempo presente junto a un docente que se vale de la contemporaneidad para no restarle futuro a su alumnado. Por ello, hacemos fuerte a la IA al lado de la usabilidad en pro de conseguir de la unión algo útil y eficaz, alejándose de la frustración. Y la corresponsabilidad con la IA pasaría por facilitar el proceso de enseñanza-aprendizaje en virtud de organizar los recursos, materiales y tareas, facilitar la búsqueda e incentivar los criterios de elección de los contenidos y que sea de ayuda en la evaluación. Estamos ante una esfera de encuentro que se adapta a las necesidades y propósitos del alumnado con una tendencia minimalista; es decir, de simplicidad, funcionalidad y armonía estética. Y todo con un resultado de *aprendencia* (Rodríguez y Bohórquez, 2018)

El principio de la usabilidad se hace fuerte en la propuesta de una codocencia compartida y tecnológica a través de lo intuitivo e impulsando la memorabilidad. Veamos el matiz entre conceptos. Lo intuitivo es la capacidad que se desarrolla para entender algo de forma inmediata y evidente; buscándose la eficiencia. Mientras que la memorabilidad es el procedimiento que se genera para un aprendizaje duradero, dejando una meridiana huella emocional y cognitiva. Por tanto, si lo memorable es algo que es digno para ser recordado... En educación también podría ser algo emocionante o conmovedor, que se hace destacable y perdurable para el alumnado.

La tecnología en foco facilitaría un ambiente colaborativo; no le quitaría el valor al docente (que actúa como líder o coadyuvante). A lo que cabría aunar una metodología activa junto a la IA para fomentar un aprendizaje enriquecido, diverso e inclusivo (Jurkowski et al., 2023).

4. LA DISTRIBUCIÓN DE TAREAS

En este caso, habría que determinarlas y diseñarlas con la presencia de las pantallas. Todo queda inspirado en los principios básicos del diseño de aula, que debe ajustarse a las necesidades del alumnado y el fomento de los espacios didácticos. Además de que se facilite la interacción en base a la colaboración permitiendo el aprendizaje apoyándose en los demás y todo con la intención de generar entornos confortables para la práctica educativa y las personas implicadas. Pero, igualmente, teniendo como referente el uso y favorecimiento de las pantallas/IA. Por ello, el diseño debe tenerse en cuenta y si es necesario su adaptación para que el alumnado pueda participar de la experiencia formativa y seguimiento de las tareas; sea de búsqueda o, hasta, de elaboración de trabajos para poder compartirlos (Espinoza y Tapia, 2023).

Las pantallas en el seno del aula codocente no son estáticas. Al igual que se ha manifestado la necesidad de un docente formado a la hora de crear un ambiente en el seno del aula, se ha de disponer todo para que el alumnado deje de ser pasivo; así como que existan diversos recursos tecnológicos, no exentos de corresponsabilidad en sus usos. Las pantallas se erigen en el gran protagonista de este apartado, pues irán a imprimir sentido diferenciador a la práctica educativa (Vidal, 2023). Por tanto, la utilización con sentido de la IA adquiere su sensatez. No solo como un mero auxiliar didáctico que está ahí para ilustrar los comentarios del docente, usándose como un agente facilitador del didactismo. Igualmente, se pueden hacer trabajos en el aula creados por la IA. Insistiremos que no consiste en restarle presencia y protagonismo a los codocentes, pues se trata de sacarle partido a todo el caudal de posibilidades con que cuenta la IA, además de las potencialidades para favorecer diálogos y resultados (Aparicio et al, 2024). Estamos pensando en texto pero, también, en fotografía, vídeo o audio. El

mérito no sería el resultado sino la implicación en el proceso a la hora de introducir los *prompts*. Junto con la posibilidad de creación de vídeos verticales por parte del alumnado, invitando a la creación o la recreación de un contenido de clase.

Un trabajo que se ha de compartir; y nutrir al grupo de estudiantes con los resultados ofrecidos con la IA. De este modo, el codocente lo puede utilizar como apoyo a sus contenidos de clase. La capacidad de este recurso para dosificar la información se convierte en la posología idónea para la práctica docente. Además, la cantidad de vídeos *reels* que existen en la red podrían ser visualizados y comentados, con el afán de crecer en capacidad crítica. El codocente imparte su contenido y, en determinado momento, la IA actúa no eclipsando su figura sino, más bien, incentivando el diálogo o la ética (Cabero y Barroso, 2025), la aclaración o la capacidad de introducir, resumir o bien concluir un determinado contenido de los abordados en el aula.

El otro matiz que quedaría con respecto al uso, en esto que hemos determinado en llamar, la distribución de las tareas, sería dotarlo de un mayor protagonismo dando la clase. No necesariamente se ha de pensar en que el codocente saldría del proceso sino que, igualmente, adoptaría otro rol. Un que-hacer permisivo que deja actuar a la IA; eso sí, previa búsqueda, selección y evaluación pero, además, de la actualización y contraste de la información para ser compartida con su alumnado. No es algo que se utiliza para eludir las responsabilidades del docente transfiriéndoselas a la IA. Aquí el docente mantiene, igualmente, un trabajo en la parte de programación del aula con un resultado de coparticipación, donde el profesorado presenta el contenido a ser impartido y la IA, por ejemplo, lo recrea. El resultado sería una manera de embellecer el contenido que, por la razón que sea, tradicionalmente se muestra árido. Pues ahora se podría encontrar, entre ambos, la posibilidad de complacerlo, como un ejercicio de “calidad para la educación” (Amar, 2009, p. 32).

Y todo no tiene que darse de modo estanco. Se pueden alternar estas modalidades de uso. Siempre visando las necesidades del alumnado, sin olvidarse los contextos y posibilidades existentes en el aula y, en ocasiones, valiéndose de recursos sencillos y polivalentes como son los pequeños proyectores inalámbricos con wifi y bluetooth.

5. ALGO DE HISTORIA

Hemos de tomar la historia como un relato inspirado en acontecimientos del pasado de consideración para darlos a conocer. No se ha de considerar este epígrafe como una relatoría donde se estudian o narran cronológicamente hechos del pasado o vestigios artísticos. En este sentido, desde Pitágoras los vasos griegos han tenido una intención educativa más allá de la ilustrativa. Los vasos griegos eran objetos didácticos que pretendían poner en valor determinados principios éticos que, fácilmente, se podrían transmitir a través de dibujos con una gran carga visual y pedagógica. Por ello, nos alejamos de los vasos o vasijas, no sin antes mencionar el de maestros y alumnos de la escuela ateniense, Vasija con figura roja (cerámica), para restaurar el concepto que prevalece a través del tiempo: *kalokagathía*. Desde antaño los griegos consideraban la *paideia* como la búsqueda para su ciudadanía del equilibrio físico, intelectual y espiritual. Un deseo que denominaron *kalokagathía*, con el cual alimentaban la pretensión de alcanzar la *areté*, es decir, la virtud como excelencia, vigor o valor, que se restablece con el poder de obrar.

A la postre, lejos de describir obras de arte de la antigua Grecia, la tendencia que estamos marcando es establecer conceptos que se derivan de aquella experiencia clásica: la estética y la creatividad (Parini, 2010). No solo en la *paideia*, la *kalokagathía* o la *areté* sino que, también, en el concepto de la *euritmia* que tanto y bueno hace al tópico de la codocencia. O sea, una *euritmia* que se arraiga en

el griego como “eu” (bello/bueno) y “rhythmos” (ritmo), que traducimos como “movimiento bello y armonioso”. En definitiva, este concepto viene a poner de relieve el valor de la armonía, alejándose del exabrupto o del protagonismo que eclipsa a un docente en beneficio del otro. El profesorado que participe de esta experiencia docente ha de compenetrarse en su quehacer. No significa que haga lo mismo o con la misma metodología; es decir, se ha de asemejar en los propósitos y resultados de aprendizaje.

Y en este entramado de conceptos de la Grecia clásica, cabría introducir otros tantos que vendrían aunar significados a la propia codocencia. El primero de ellos sería el de *poiesis*, un término relevante en nuestro argumento pues cabría traducirse como el hecho de hacer o, aún mejor, de crear. Un creador (*poietés*), que estaría en la esfera del saber alejado de la repetición y está preocupado en su producción; es decir la *techné*. De la misma manera que estaría próximo a la acción ética de la *praxis* en búsqueda de la producción del saber; con el matiz clásico de que la *praxis* posee en sí una finalidad: la de actuar bien y en beneficio de los demás. En alusión al término *poiesis*, Platón en el Banquete (1983, p. 83), establece luz al respecto:

“Sabes que el concepto de ποιήσις es algo muy amplio, ya que ciertamente todo lo que es causa de que algo, sea lo que sea, pase del no ser al ser es creación, de suerte que todas las actividades que entran en la esfera de todas las artes son creaciones y los artesanos de éstas, creadores o «poetas»”.

Estamos frente a la figura del *poietés* o creador, a los que asemejamos con los posibles docentes que intervengan en el proceso de codocencia. Ya que lo que se pretende es la *autopoiesis* o que la experiencia compartida se mantenga y obtenga sentido.

6. UN POCO DE ACCIÓN

El sentido de la profesión se engrandece por la presencia del alumnado. Tal vez, se podría pensar que el éxito de que el aula esté repleta de estudiantes radique en la versatilidad del docente y nos olvidamos que, en gran medida, todo reside en la obligatoriedad de la presencia del alumnado. La tradición centrada en el *magistrocentrismo* con aquel enfoque pedagógico medido en la figura del docente (Joyce y Weil, 1985), en su saber hacer, convencer o en su modo de evaluar, se ha ido orientando hacia un mayor protagonismo y mirada sobre el alumnado, o *paidós* (del griego: niños). Lo que ha generado toda una tradición de acción vinculada con el *paidocentrismo* (Gutiérrez, 2023). Una visión con una larga tradición pedagógica, incluso descrita por Comenio desde el momento que lo enuncia como una parte en el proceso que ha de estar activada, incentivada a que aprenda por descubrimiento y se encuentre motivado. Con ello, activación, descubrimiento y motivación se convierten en la antesala de la innovación, como aquella necesidad de mejorar, como ejercicio pensado en los demás para que adelanten y acrecienten el conocimiento (Amar 2021).

Igualmente, queda superado el enfoque exclusivo que hace alusión al logocentrismo, el cual está centrado en el contenido que es transmitido por el docente y asumido por el estudiante. La acción entra en escena, en el seno del aula, cuando lo que se procura es que el alumnado deje la pasividad y se haga copartícipe del proceso de enseñanza-aprendizaje. El conocimiento se construye entre las partes y los recursos del aula. Cuanto más y mejor, mayor será el aprovechamiento del saber por parte del alumnado. De este modo, el estudiante irá a contribuir y participar de la construcción del conocimiento. Máxime cuando en el aula, entran en acción, más de un relato. Incluso pueden ser contrapuestos y que se abra una ventana a la discrepancia del estudiante. Una propuesta de aprendizaje disruptivo y

contrahegemónico (González et al, 2024), que bajo este paraguas se cuestiona el método tradicional, haciendo que el estudiante se erija como referente. Siendo el centro del proceso, además de ganar en solvencia y posicionamiento activo. Ya no solo se ha superado el modelo unidireccional de docente al discente que puede conjugarse con el bidireccional (gracias al diálogo); sino que se hace fuerte el multidireccional y, a la vez, multipersonal y, como propuesta, aunándose a la IA (Cárdenas, 2024). Probablemente, se enriquece la acción y la producción, la manera de proceder y acceder al conocimiento para, luego, hacerlo suyo y compartirlo.

Un aprendizaje disruptivo que no solo irá a flexibilizar los espacios de acción sino que, asimismo, presentará la posibilidad al profesorado implicado de erigirse como facilitador y hacer de la curiosidad la antesala del aprendizaje, pues incentiva la motivación. Además, que se empieza a hablar de un aprendizaje contrastado. Lejos quedaría el discurso transmisor del docente, de la pura memorización, de la presión a la evaluación convencional, así como de un currículum fijo por otro más optimista (Carmona et al., 2021).

La acción se torna en posible y el alumnado opta por un aprendizaje activo y práctico, además de interdisciplinar, pues las fronteras del punto de vista del único docente en el aula, se quiebran ante varias perspectivas, discursos o recursos.

7. DESDE LA CULTURA DE AULA

El ejercicio pedagógico de la codocencia se engrandece desde el momento en que se ha generado y mantenido una buena cultura de aula. Ahora bien, siempre y cuando el concepto de buena cultura de aula se haga coincidir y se dé cita con la idoneidad de los valores, las normas internas y las prácticas educativas en el seno del espacio donde se vaya a impartir la docencia compartida.

Una cultura de aula que se enriquece con la diversidad y que sea un pretexto para llegar a gestionar todo lo bueno que en ella emana, fomentándose la empatía, el respeto hacia todas las personas que se dan cita. Además de que se fomente la colaboración en beneficio del aprendizaje, el desarrollo del espíritu crítico, la autonomía y la autoestima de y entre los implicados (Rivas, 1992).

En este contexto teórico sobre la codocencia, introducimos el aprendizaje en situación (en la práctica), el cual se nutre del quehacer y la sensibilidad de al menos los dos docentes (sin haberse descartado la presencia de las pantallas). Ahora todos contribuyen al desarrollo de una cultura de aula con tendencia a la idoneidad que se inspira en la colaboración y en la creatividad. Pero, igualmente, en el diálogo y en la participación de todos los implicados en el proceso de enseñanza-aprendizaje que se nutren y contribuyen a la construcción del conocimiento y la convivencia armónica.

En el seno del aula codocente, la forma de actuar del profesorado genera el desarrollo de la cultura docente moldeando sus prácticas educativas, siempre anclados al máximo respeto a los grupos y a los diferentes ritmos de aprendizaje de los discentes. A la cultura codocente cabría añadir la cooperación y el hecho de fomentar las diversas actuaciones compartidas e innovadoras (Díaz y Macías, 2022). Lo que iría a generar una propicia cultura profesional codocente, convirtiéndose en una experiencia que engrandece el proceso formativo.

Ahora bien, en todo ello se requiere formación docente (García y Souto, 2023). De modo que la cultura de aula se instala en la necesidad de una estimable formación docente. Es decir, la cultura de aula adquiere un desenvolvimiento cualitativo aunándose a la cultura docente/codocente, para desembarcar en una apreciada cultura profesional con formación.

En este epígrafe que hemos determinado en denominar inicialmente, desde la cultura de aula, se ha enriquece con la cultura docente y profesional, aunando el concepto de compromiso y el de cor-

responsabilidad entre todas las personas implicadas en la labor, según “lo conveniente, lo deseable, lo posible” (Forestello, 2021). A todas luces, lo que se persigue es el desarrollo de precisas competencias en el profesorado. Y todo ello, en beneficio de generar una cultura pedagógica en el aula pro docente.

Lo que se iniciaba con un balbuceo sobre la cultura de aula, después de varias reflexiones en torno a las necesidades formativas profesionales, se ha convenido focalizar sobre la cultura pedagógica en el aula impulsada por docentes. Cerrándose la trama sobre: la cultura de aula, la cultura docente/codocente, las competencias profesionales del profesorado implicado y la cultura pedagógica en el seno del aula (Toro, 2014).

8. CONCLUSIÓN

Concluir en un discurso en continua construcción es algo complicado, un riesgo o una presunción. En este caso, concluir va más allá de acabar, o bien determinarlo como el remate que finaliza. Es ahora cuando invitamos a que el lector comience a replantearse la posibilidad de la codocencia como una posible coexistencia de lo presencial y lo virtual. Tal vez, se han establecido pautas para iniciar el debate. Seguramente, algunas se hayan manifestado y, por ello, han quedado más claras. Pero la idea no ha sido otra que la de invitar a reflexionar sobre la codocencia y su cohabitación con lo ya establecido y lo que está emergiendo. Por ello, requiere de todas las personas implicadas en la educación la voluntad de seguir aprendiendo, de no quedar anclado al pasado y fomentar la inclusión (López y Galarraga, 2024). Al menos, valorar lo mejor del pasado para que se dé cita con lo bueno que nos ofrece el presente y el futuro inmediato.

En este contexto, la IA ha emergido y ha generado ciertas emergencias. Más allá del alarmismo propio de lo nuevo, como suceso sobrevenido, se realiza una llamada para mantenerse en alerta; es decir, atento a lo que ya hay y a lo que pudiera llegar. La codocencia no ha quedado exenta de la contemporaneidad y el pensamiento crítico (Grayson, 2023). La codocencia está, íntimamente, ligada a la educación del siglo XXI. Es cierto que siempre existió y estuvo vinculada a la tecnología de su momento. En este caso, no ha de ser diferente. Ahora bien, hemos de exigirnos una formación permanente para no hablar en tiempo pasado y hacer de nuestro discurso y práctica educativa un referente de la contemporaneidad.

Y es cuando adquiere sentido la labor del docente (Rawls, 2022). Es el momento cuando se erige en copartícipe del complejo hecho de enseñar. La diversidad y la inclusión se tornan un referente pues todos en algún momento necesitamos de apoyos, sean en los otros o con las herramientas tecnológicas. Los presentamos como agentes de socialización y de apoyatura para facilitar el proceso y, en las medidas de las posibilidades, engrandecerlo.

En este entramado es cuando actúa la IA como facilitadora, no exenta de toma de decisiones para su mejora (Innerarity, 2025). Nunca ha de verse como aquel recurso tecnológico que iría a restar protagonismo al docente. Se podría hablar de corresponsabilidad y, sobre todo, de cocreación.

Aquí se añadiría la necesidad de una formación docente para promover en el seno de la clase una idónea cultura de aula. Un educador cualificado que sepa de pedagogía, didáctica y tecnología. Para poder expresarse y enseñar en pleno siglo XXI, con las herramientas de su tiempo.

Con un docente formado y sensible la práctica de la enseñanza compartida se hará más dúctil y, con ello, se abrirán nuevos horizontes para implementar procesos de enseñanza-aprendizaje más justos. Un beneficio que irá para todo el alumnado. Docentes que trabajan en conjunto para superar la exclusiva cultura individualista de la docencia y la pasividad en el alumnado (Hargreaves, 2019).

Estamos ante un alegato para sostener nuevas maneras de llevar a cabo la práctica educativa, que pasa por saber promover la eficacia como aquella capacidad de lograr el efecto deseado.

Ojalá, estemos ante un hecho codocente donde el alumnado atesore en el seno del aula, según Paulsrud y Nilholm (2023), una experiencia educativa con mayor atención y apoyo. Y, además, como apuntan Giró y Sancho (2022), en alusión a la IA, que estamos ante una herramienta de ayuda capaz de reducir la complejidad de los temas educativos y del propio aprendizaje. Y, de este modo, la codocencia posibilite una inteligente coexistencia, o viceversa.

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6. Social Robotics in an Educational Context: Initial Perceptions of Future Teachers

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Abstract: Social robotics is an emerging field within educational technology and has sparked growing interest in initial teacher training. However, before incorporating these resources into educational practice, it is necessary to understand how prospective teachers perceive them, and what expectations and reservations their use generates. This paper presents a pilot study conducted with 51 teacher training students at the University of Alicante, prior to their participation in sessions with social robots. The aim was to analyse their initial perceptions regarding the educational use of social robotics. The research adopted a descriptive quantitative approach. An anonymous, voluntary questionnaire was used to collect data, comprising Likert-scale rating items, dichotomous questions and sociodemographic variables. The instrument was designed based on dimensions linked to models of technology acceptance and took the UTAUT model as a partial reference, particularly regarding aspects related to perceived usefulness, trust, acceptance and initial disposition towards the use of social robots. Furthermore, specific items were included on the role of teachers, responsibility in pedagogical decision-making and possible reservations regarding the incorporation of social robots in educational contexts. The responses, collected in February 2026, were analysed in aggregate form to identify general trends. The results reflect an initial open attitude towards social robotics, particularly due to students' interest in exploring its educational potential and their recognition of its possible usefulness in the classroom. However, they also reveal a cautious stance: future teachers harbour doubts about the trust they could place in a robot, express caution regarding its use in teaching, and clearly reaffirm that pedagogical decisions must remain the responsibility of teachers. The study provides an initial basis for designing future training experiences with social robots in initial teacher education.

Keywords: social robotics, initial teacher education, emerging technologies, higher education.

1. INTRODUCTION

Social robotics has established itself in recent years as a significant area within educational technology (Ackermann et al., 2025). Compared to other digital resources, social robots incorporate physical presence, verbal and non-verbal interaction, responsiveness and participation in guided activities. These characteristics open up new possibilities for educational mediation, particularly in initiatives focused on communication, motivation, participation and support for learning tasks.

As Arocena et al. (2022) point out, in the classroom, social robots can fulfil various functions: supporting communicative activities, energising group work, asking questions, stimulating pupils' curiosity, or acting as a mediating resource in specific learning experiences. However, their incorporation cannot be reduced to the mere introduction of a novel technology. It requires prior pedagogical reflection on the purpose of use, the role of teachers, the type of interaction being promoted, and the limits that must be established for appropriate educational application.

This issue takes on particular importance in initial teacher training. Future teachers are preparing to work in contexts where emerging technologies will be the tools of the future; it is therefore essential that teacher training students are familiar with these resources, analyse their potential and critically assess their implications.

For this reason, it is not enough to describe the technical characteristics of social robots. It is also necessary to understand how those training to become teachers perceive them. Their initial perceptions can influence their willingness to explore these technologies, the educational value they attribute to them, and the degree of trust they place in them. Furthermore, they enable the identification of specific training needs before designing teaching experiences with social robots.

2. THEORETICAL BACKGROUND

2.1. Social robotics as an emerging educational technology

Social robotics forms part of the emerging technologies applied to education and is characterised by the introduction into the classroom of devices capable of interacting with people through spoken language, movement, gestures, programmed responses or artificial intelligence systems (Martinez-Roig et al., 2023). Unlike other digital resources, the social robot alters the educational setting, as it occupies a visible position in the space, directs messages to pupils and can participate in activities designed by teachers, moreover from a multimodal perspective, as noted by Bian et al. (2025), Duncan et al. (2024) and Ekström & Pareto (2022).

These interactive features explain part of the interest that social robotics has generated in the educational field (Wang & Cheung, 2024). The literature has indicated that social robots can act as tutors, learning partners or activity facilitators, with potential effects on student participation, motivation and certain cognitive and affective outcomes.

However, their educational value does not depend solely on their technical capabilities (Lampropoulos, 2025). A social robot does not, in itself, improve a learning situation. Its contribution is linked to pedagogical design, the purpose of the activity, the type of interaction proposed and the role that teachers assign to it, as we have previously noted (Martinez-Roig, 2024a). Therefore, social robotics should be understood as an educational resource mediated by teaching decisions, not as an automatic solution for innovation in the classroom.

Recent reviews emphasise this point (Bonaiuti et al., 2022; Deng et al., 2024). Social robots can facilitate more interactive learning experiences, but they also pose challenges related to teacher training, privacy, technological dependency, the appropriateness of content, and the sustainability of their use in real-world contexts. Donnermann et al. (2020) note that the field offers potential benefits, although significant challenges remain for its stable educational application.

2.2. The social robot as a mediator in educational processes

The educational value of social robotics lies not merely in the incorporation of a technological device into the classroom, but in the possibility of introducing a physical and interactive agent that participates in specific teaching situations (Bakhoda et al., 2026). From this perspective, the social robot can be understood as an educational mediator: a resource that acts as an intermediary between teachers, students and the activity, with the aim of facilitating specific forms of interaction, participation and support for learning.

Social robots can fulfil a variety of roles (Baksh et al., 2026). In some settings, the robot acts as a tutor or task guide; in others, it takes on the role of a learning partner, conversation partner, communication aid or facilitator of the activity, including in STEM contexts (Ahmad et al., 2020). Arocena et al. (2022), in their systematic review on the subject, have highlighted precisely this diversity of roles, identifying robots that participate as tutors, peers or assistants in teaching and learning situations.

This mediating function is particularly relevant because the robot introduces a form of interaction that differs from that of other digital resources (Baxter, 2025). Its appearance, its ability to convey messages, respond, move or direct students' attention can alter the dynamics of the activity. Consequently, the robot can foster curiosity, increase initial engagement and serve as a stimulus for participation, provided that the teaching approach is well designed, as indicated by Zinina et al. (2022). The available evidence points to positive effects in certain educational experiences, such as the use of the Pepper robot (Kulet et al., 2022; Pandey & Gelin, 2018). However, the results depend on the context, the age of the students, the type of task and the design of the intervention.

However, as Woo et al. (2021) point out, conceiving of the robot as a mediator also implies recognising its limitations. The robot does not replace the pedagogical relationship nor does it displace the teacher's responsibility. Its role must be integrated into a teaching sequence planned by the teacher, with clear objectives, defined timeframes and explicit educational criteria. In this sense, the robot can support the activity, encourage certain interactions or boost motivation, but pedagogical interpretation, decision-making and educational guidance remain the responsibility of the teacher (Drobnjak et al., 2025; Mahmoud, 2025).

This idea is particularly important in initial teacher training. If teacher training students perceive the robot merely as a novelty, its use may be reduced to a one-off experience. Conversely, if they interpret it as a mediator serving specific educational objectives, they can analyse in greater depth which tasks are appropriate, which interactions can be promoted, and which limits must be respected at non-university levels (Banko et al., 2025). Thus, initial training must help shift the focus from a view centred on technological novelty to a pedagogical view centred on activity, the educational relationship and the professional role of the teacher.

Furthermore, robotic mediation raises specific questions regarding trust, autonomy and pedagogical control, as noted by Engwall & Lopes (2022) in an adult education context. The robot may participate in the classroom, but the extent of its involvement must be clearly defined. Some research on teachers' acceptance of robots, such as that by Tutul et al. (2026), reveals favourable attitudes, though also varied and as yet unconsolidated responses, reinforcing the need to study how teachers perceive these technologies before integrating them into training programmes.

Therefore, analysing the social robot as a mediator allows the debate to be situated at a midpoint between technological enthusiasm and preventive rejection, as indicated by Tutul et al. (2026). The main question is not whether or not the robot should be in the classroom, but what role it can play, under what conditions, and for what educational purpose. This perspective is consistent with the aim of the present study, which focuses on understanding the initial perceptions of future teachers regarding educational social robotics. In this regard, there has been some research on the subject, such as that conducted by Burdett et al. (2022), but concerning children and adults; that by Beuscher et al. (2017), but involving older adults; that by Berghe (2022), concerning language learning; or that by Belpaeme et al. (2018), which utilised outdated references.

From this perspective, we aim to answer the following research questions: a) What prior familiarity do trainee teachers have with social robotics?; b) What educational value do trainee teachers attribute to social robots in teaching and learning contexts?; c) What degree of trust, acceptance and willingness towards the use of social robots do trainee teachers demonstrate?; d) What possibilities and reservations do prospective teachers perceive regarding the incorporation of social robots into the classroom?

3. OBJECTIVES

The overall objective of the study was to analyse the initial perceptions of teacher training students, as future teachers, regarding the educational use of social robotics prior to their participation in practical sessions with social robots.

The following specific objectives were derived from this general objective:

- a) To identify the students' prior level of familiarity with social robotics and other emerging technologies.
- b) To analyse the educational value that future teachers attribute to social robots in teaching and learning contexts.
- c) To examine the level of trust, acceptance and willingness regarding the use of social robots in the classroom.
- d) To explore the possibilities and reservations perceived by students regarding the incorporation of social robots into teaching practice.

4. METHOD

The study adopted a descriptive quantitative approach (Hernández-Sampieri & Mendoza, 2023), with a pilot design aimed at understanding the initial perceptions of future teachers regarding the educational use of social robotics. The research was conducted prior to the students' participation in practical sessions with social robots; therefore, the data reflect a preliminary assessment based on expectations, initial familiarity and openness towards this technology. Data collection was carried out using a questionnaire (Meneses, 2016), and the analysis focused on the description of frequencies, percentages and basic descriptive measures of the items included in the instrument.

4.1. Context and participants

The study was carried out with teacher training students at the University of Alicante, as part of a training experience prior to direct work with social robots. The research was a pilot study and was designed as an initial exploration of future teachers' perceptions of educational social robotics.

The sample consisted of 51 participants and was selected using purposive non-probabilistic sampling, as the groups of students involved in the planned training programme took part. All participants voluntarily agreed to take part in the study after reading the introductory information in the questionnaire. This information stated that participation was anonymous and voluntary, that there were no right or wrong answers, and that the data would be processed in aggregate form for academic purposes.

4.2. Instrument

An *ad hoc* questionnaire was used to collect the data. The instrument included Likert-type rating items (Tutz, 2020), dichotomous questions and sociodemographic variables. Its purpose was to ascertain the students' initial perceptions of social robotics prior to participating in the planned sessions with social robots. The questionnaire was partly designed based on dimensions linked to the UTAUT model (Martinez-Roig, 2024b), particularly those related to perceived usefulness, acceptance, trust and willingness to use the technology. , however, the instrument does not fully replicate the model, as it also incorporates specific items on the role of the teacher, pedagogical responsibility, possible reservations regarding social robots, and the perception of their usefulness in educational contexts.

4.3. Procedure

Before completing the questionnaire, the students were provided with initial information regarding the purpose of the study. It was explained that the aim was to ascertain their prior opinions as future teachers before participating in sessions with social robots. It was also stated that the questionnaire did not assess technological knowledge and that the responses should reflect their personal perceptions.

Participation was voluntary and anonymous. Informed consent was obtained at the start of the form via a tick box. Only those who confirmed they had read the information and agreed to take part in the study participated. Responses were collected via an online form and subsequently exported to a spreadsheet for analysis.

4.4. Data analysis

The data analysis took a quantitative, descriptive approach. Responses were analysed in aggregate form, with the aim of identifying general trends in the students' initial perceptions.

The frequencies and percentages of dichotomous responses and sociodemographic variables were reviewed. For Likert-type items, basic descriptive measures were calculated to assess the trend of responses regarding the study's main dimensions: prior familiarity, perceived educational utility, trust, acceptance, willingness to use social robots, and reservations about their incorporation into the classroom. The analysis enabled the results to be organised into five sections: participant profiles, prior familiarity with social robotics and emerging technologies, perceived educational utility, trust and acceptance, and the possibilities and reservations perceived by the future teachers.

4.5. Ethical considerations

The study was conducted within the framework of the project "Use of social robots for educational purposes", with ethical approval from the University of Alicante and authorisation to carry it out at the Faculty of Education. The research included specific participant information and informed consent forms, which explained the study's objectives, the voluntary nature of participation, the possibility of withdrawing from the process at any time, and the confidential treatment of data.

Participants were informed that the data would be used for academic research purposes and would be processed in an aggregated and coded form. Where images, voice recordings or audiovisual recordings were collected, express and specific authorisation was sought, in accordance with the project's informed consent form. Furthermore, the research protocol provides for the use of questionnaires, interviews, observations and, where appropriate, interaction logs, always with the information being treated confidentially and in coded form.

5. RESULTS

5.1. Profile of the participants

The sample consisted of 51 participants from the University of Alicante's Teacher Training programme, mainly enrolled in the second year. The gender distribution shows a clear predominance of women: 47 participants identified as women, representing 92.2% of the sample; 3 participants identified as men, 5.9%; and 1 person preferred not to answer, 2.0%.

In terms of age, the majority of participants were in the early years of their university studies. The mean age was 19.2 years, with a range of 18 to 31 years. The largest group was the 18-year-olds, with 30 participants, followed by the 19-year-olds, with 11 participants. This distribution is consistent with a study conducted in the context of initial teacher training.

5.2. Prior familiarity with social robotics and emerging technologies

The data show a very high level of familiarity with artificial intelligence tools, but very limited experience with social robots. Specifically, 50 of the 51 participants indicated that they had previously used artificial intelligence tools such as ChatGPT or similar ones, representing 98.0% of the sample. This figure reflects that the students already live alongside emerging technologies in their daily lives, although not necessarily with robotic technologies.

The situation changes markedly when asked about previous contact with social robots in educational or training contexts. Only 4 participants answered in the affirmative (7.8%), whilst 47 stated they had no previous contact (92.2%). Therefore, social robotics appears to be a technology with which students have little direct experience, despite their high level of prior exposure to artificial intelligence tools.

Regarding self-perceived digital competence among teachers, the average was 3.25 out of 5. The majority fell at the midpoint of the scale: 37 participants chose option 3. Only 12 people rated themselves at high or very high levels, whilst 2 rated themselves at a low level. In contrast, general interest in educational innovation was higher, with an average of 3.92 out of 5. A total of 39 participants were at high or very high levels. These results point to a profile characterised by an interest in innovation, but with teachers' digital competence still perceived as intermediate.

5.3. Perceived educational value

The educational value of social robots received a moderately positive rating. The item "I believe that robots can play a useful role in education" achieved an average score of 3.63 out of 5. In this case, 29 participants agreed or strongly agreed (56.9%); 19 held a neutral position (37.3%); and only 3 disagreed (5.9%).

There is also notable interest in exploring the potential of robots in teaching. This was one of the highest-rated items in the questionnaire, with an average of 4.10 out of 5. A total of 38 participants, 74.5%, agreed or strongly agreed with this statement. This result indicates that, although the students have had no previous contact with social robots, there is a clear willingness to explore their potential educational applications.

Comfort with interacting with a robot in an educational context received a more moderate average score of 3.29 out of 5. On this item, 17 participants (33.3%) agreed or strongly agreed; 25 (49.0%) chose the middle option; and 9 (17.6%) disagreed. Therefore, usefulness and interest appear to be more strongly felt than initial comfort. Students seem open to exploring social robotics, but do not yet express clear confidence regarding direct interaction.

5.4. Trust, acceptance and willingness to use social robots

The results show a cautious initial acceptance. The presence of robots in educational settings does not generate widespread rejection, though nor does it indicate fully established acceptance. The item regarding discomfort with robots scored an average of 2.86 out of 5. Regarding this statement, 15 participants disagreed or strongly disagreed (29.4%); 24 took a middle ground (47.1%); and 12 agreed (23.5%). This indicates that discomfort exists among a portion of the sample, but it is not the dominant trend.

Trust emerges as a particularly relevant dimension. The item "I would find it difficult to trust a robot during an educational activity" scored an average of 3.45 out of 5. A total of 26 participants, 51.0%, agreed or strongly agreed with this statement. This result shows that trust in the robot still

represents a significant reservation. Students may recognise its educational utility and interest, but remain cautious about the possibility of trusting the robot during an activity.

The initial intention to use the robot was also moderate. The item “I would consider using a social robot in my future teaching practice” scored an average of 2.90 out of 5. Only 11 participants, 21.6%, agreed or strongly agreed; 24 were in an intermediate position, 47.1%; and 16 disagreed, 31.4%. For the item “If I had a suitable social robot, I would consider integrating it into the classroom”, the average rose to 3.24 out of 5, with 20 participants agreeing or strongly agreeing, 39.2%. This suggests that the intention to use improves when the existence of a suitable robot is considered, although a significant degree of indecision remains.

The item “I see it as possible to use social robots as an educational resource in my future career” obtained an average of 3.18 out of 5. Half of the sample, 26 participants, chose the middle option. This data reinforces the idea of an attitude still in the making: future teachers do not reject social robotics, but they need training experiences, pedagogical criteria and clear conditions to assess its potential use in teaching with greater confidence.

5.5. Possibilities and reservations perceived by future teachers

The responses show a very clear defence of the central role of teachers. The item “Ultimate responsibility for educational decisions must lie with the teacher” achieved an average score of 4.33 out of 5. A total of 41 participants, 80.4%, expressed ‘ ’ or ‘total agreement’. Even more clearly, the statement “Technologies can support teaching, but the teacher’s professional judgement must remain central” scored an average of 4.51 out of 5, with 46 participants agreeing or strongly agreeing, 90.2%.

A strong perception of professional autonomy is also evident. The statement “I feel capable of deciding independently when to use a technology and when not to” scored an average of 4.29 out of 5. In this case, 46 participants agreed or strongly agreed. Similarly, professional judgement as a guide for the use of any technological resource scored an average of 3.98 out of 5, with 70.6% of responses agreeing or strongly agreeing.

Reservations arise, above all, in relation to the possible change in the teacher’s role. The item “The advancement of social robotics in education may generate uncertainty regarding the professional role of the teacher” scored an average of 3.55 out of 5. A total of 31 participants, 60.8%, agreed or strongly agreed. This data indicates that students perceive social robotics as a technology with potential, but also as a resource that may raise questions about the teaching profession. In contrast, the idea of teachers being replaced does not appear to be a dominant perception. The item “It is likely that a social robot will come to replace key teaching functions” scored an average of 2.82 out of 5. Only 13 participants, 25.5%, agreed or strongly agreed; 21 disagreed or strongly disagreed, 41.2%; and 17 held an intermediate position. Therefore, the majority of students do not appear to hold a view that social robots will replace teachers, although they do recognise that certain technologies could transform some teaching functions.

6. DISCUSSION

The results suggest that student teachers’ perception of social robotics is one of cautious openness. Future teachers recognise that social robots may play a useful role in education and show an interest in exploring their potential, but this initial interest has not yet translated into full acceptance or a clear intention to use them professionally. The intermediate responses on several items indicate that the students’ perception is still in an exploratory phase. This finding is consistent with recent literature,

which positions social robotics as a field with educational potential, albeit dependent on the context, pedagogical design and prior experience of those participating in the activity (Ackermann et al., 2025; Lampropoulos, 2025; Wang & Cheung, 2024).

The limited direct experience with social robots helps to explain this caution. Although almost the entire sample reported having used artificial intelligence tools, prior contact with social robots in educational contexts is very limited. This difference suggests that students are familiar with emerging digital technologies, but not necessarily with robotic devices that incorporate physical presence, multimodal interaction and situated response. In this regard, the findings align with studies highlighting the specificity of human-robot interaction, as the robot is not perceived as a conventional digital tool, but rather as an agent with a visible presence in educational activity (Bian et al., 2025; Duncan et al., 2024; Ekström & Pareto, 2022). Likewise, recent work linking artificial intelligence and social robotics, such as that by Bertacchini et al. (2023), shows that this convergence can broaden the possibilities for interaction, although it also requires a more careful analysis of acceptance, trust and limits of use.

Trust is one of the most significant elements of the study. Students recognise the educational potential of the robot, but a significant proportion state that they would find it difficult to trust it during a learning activity. This finding is significant because social robotics introduces a relational dimension that can generate interest, but also doubts regarding the device's reliability, control over the activity, and the role it should play within the classroom. This finding aligns with research that has highlighted the importance of technological acceptance, interaction and user experience in educational contexts involving social robots (Donnermann et al., 2020; Tutul et al., 2026). It is also related to studies focusing on interaction and collaboration with robots in educational processes, where trust depends on the clarity of the task, the support provided and the type of relationship established with the device (Engwall & Lopes, 2022).

Another key aspect is the defence of professional teaching standards. The responses show that the majority of students do not view the social robot as a substitute for teachers. On the contrary, they believe that educational decisions should remain the responsibility of teachers and that technology should play a supporting role. This perception aligns with the idea of the social robot as an educational mediator: a resource that can facilitate certain interactions or energise activities, but which requires clear lesson planning and professional supervision. This interpretation is consistent with reviews that have described social robots as tutors, assistants, learning partners or mediators, always depending on the design of the activity and the educational intent (Belpaeme et al., 2018; Woo et al., 2021). In the same vein, the literature warns that the value of the robot does not stem from its mere presence in the classroom, but from its integration into a teaching programme with defined objectives (Bonaiuti et al., 2022; Martinez-Roig, 2024a).

Uncertainty regarding the teacher's role emerges as a significant concern. Students do not appear to adopt a view of direct replacement, but they do recognise that social robotics can transform certain functions or raise questions about the teaching profession. This perception is particularly relevant in initial teacher training, as it highlights the need to approach these technologies from a pedagogical and professional perspective, rather than as a mere technical demonstration. The results align with approaches that emphasise the need to preserve pedagogical control, teaching responsibility and ethical conditions of use, particularly when social robots are introduced into real educational settings (Drob-njak et al., 2025; Mahmoud, 2025). Thus, social robotics can be understood as a support resource, but it requires clear criteria regarding privacy, autonomy, supervision, safety and educational purpose.

The data also allow us to refine the relationship between perceived usefulness and intention to use. Students recognise that robots can be useful and show curiosity about exploring their possibilities, but

their willingness to use them in future teaching practice is more moderate. This gap between interest and potential use is evident in research on the acceptance of robots in educational contexts, where a favourable attitude does not always translate into an intention to adopt them if there is a lack of direct experience, technical support, training or suitable institutional conditions (Donnermann et al., 2020; Tutul et al., 2026). In the case of initial teacher training, this finding points to the need to design practical experiences where students can observe, test and evaluate the robot in specific teaching situations.

In this regard, the findings reinforce the desirability of incorporating training experiences with social robots into the preparation of future teachers. These experiences should enable students to analyse the robot as a mediator of activities, assess its potential contribution to communication, participation or learning support tasks, and discuss its limitations. Research focusing on the use of robots as study companions, reading mediators or learning support tools shows that their potential increases when there is a structured activity and a clear educational purpose (Bakhoda et al., 2026; Baksh et al., 2024; Banko et al., 2025). Therefore, initial training should move from curiosity about technological novelty to the development of teaching criteria regarding when to use the robot, for what purpose, under what conditions, and with what pedagogical limits.

7. CONCLUSIONS

This pilot study has provided an insight into the initial perceptions of teacher training students regarding the educational use of social robotics. The results show an open attitude towards these resources, particularly due to the students' interest in exploring their possibilities and their recognition of their potential usefulness in educational contexts. However, this openness coexists with a cautious stance, marked by doubts regarding trust, comfort with interaction, and intentions for future use.

One of the study's main contributions is the identification of a clear distinction between technological interest and professional disposition. The students show curiosity about social robotics, but require specific training experiences to assess its integration from pedagogical criteria. This issue is particularly relevant in initial teacher training, where exposure to emerging technologies must be accompanied by reflection on their purpose, limitations and conditions of use. The data also show that the majority of future teachers do not view social robotics as a substitute for the teacher. On the contrary, the responses reflect a clear defence of professional judgement, pedagogical autonomy and teachers' responsibility in educational decision-making. From this perspective, the social robot can be understood as a support or mediation resource, always integrated into clear lesson planning.

Among the study's limitations, it is worth noting its pilot nature, the sample size and the use of a descriptive design focused on initial perceptions. Furthermore, the responses were collected prior to participation in sessions with social robots, meaning the data reflect prior expectations rather than a subsequent assessment based on direct experience.

As future lines of research, it would be useful to compare students' perceptions before and after interaction with social robots, expand the sample to other university years and contexts, and incorporate qualitative techniques such as interviews or focus groups. These approaches would allow for a better understanding of which factors favour the acceptance of social robotics, which reservations persist after direct experience, and which pedagogical conditions are necessary for its use in teacher training.

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7. Students' Digital Literacy and the Role of School Initiatives

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Abstract: This chapter examines the role of school initiatives in shaping students' digital literacy within contemporary educational environments. It outlines the conceptual foundations of digital literacy, reviews relevant literature, and analyzes empirical findings derived from a sample of teachers in primary and secondary education. The chapter highlights teachers' perceptions of digital infrastructure, professional development, school leadership, and students' digital competencies. It also discusses emerging challenges and identifies systemic factors influencing the effective integration of digital tools into teaching and learning. Based on the analysis, the chapter proposes solutions and recommends and outlines future research directions aimed at strengthening digital readiness in schools.

Keywords: Digital Competence, Educational Technology, School Leadership, Instructional Practices, Teacher Training, Digital Infrastructure, Learning Environments, Professional Development, Critical Evaluation, Student Skills, Innovation Policy

1. INTRODUCTION

1.1 Introduction to the Issue of Digital Literacy

In the modern era, where technological developments radically affect all areas of human activity, digital literacy is a basic skill for the individual's participation in the information society. The ability to use digital tools is no longer limited to the knowledge of how to operate electronic devices; it extends to complex skills such as critical evaluation of information, responsible online behavior, collaboration and communication in digital environments, as well as the creative use of technologies to produce new knowledge.

The global educational community has recognized that these skills are essential for the 21st century, as they affect the learning process, the professional prospects of young people, and their general social integration. As digital technologies are increasingly integrated into everyday life, schools are called upon to play a catalytic role in shaping students who can not only use technology but also understand, judge and utilize it in a responsible and creative way.

1.2 The Role of the School in the Formation of Digital Skills

The educational unit is one of the most important factors in the cultivation of digital literacy, as it is an environment where students are systematically exposed to organized learning experiences. Through targeted school initiatives, a curriculum that integrates technology and teachers who utilize digital media in daily teaching practice, the school can function as a lever for the development of digital skills.

In the last decade, many countries have promoted national or regional digital education strategies, emphasizing actions such as:

- strengthening digital infrastructure,

- introducing and utilizing digital materials and educational software,
- professional development of teachers,
- adopting pedagogical approaches that promote collaborative and inquiry-based learning through ICT.

However, the effectiveness of these initiatives depends largely on the school culture, the readiness of teachers and the quality of planning of actions.

1.3 Necessity and Contemporary Challenges

Despite the progress that has been made internationally, achieving a high level of digital literacy remains a significant challenge for many education systems. In addition to the technological infrastructure, issues such as:

- inequalities in access to digital media,
- the lack of adequate training and support for teachers,
- the difficulty of integrating technology in a pedagogically meaningful way,
- differences between schools in terms of culture, organization and resources.

Furthermore, the need for critical digital literacy—that is, the ability to evaluate the reliability of information, protect personal data, understand the risks of digital communication and adopt responsible practices—makes it imperative to reflect on existing school practices.

1.4 Purpose and Research Questions of the Study

The present study seeks to explore the way in which school initiatives contribute to the development of students' digital literacy and to capture teachers' perceptions of their role in this process. Specifically, the study aims to:

- examine how teachers perceive the strategies and programs implemented in their schools,
- highlight the degree of effectiveness of school initiatives,
- identify best practices for enhancing digital competence,
- explore the obstacles that limit the success of interventions,
- assess the role of school organization, technological infrastructure and continuous professional development in promoting digital skills.

The research questions guiding the study include:

1. What school initiatives are implemented to enhance students' digital literacy?
2. How do teachers perceive the effectiveness of these initiatives?
3. What obstacles and challenges arise during their implementation?
4. What practices and factors contribute to the successful cultivation of digital skills?
5. How do school leadership, planning and teacher training influence the overall process?

2. BACKGROUND

2.1 Definition and Evolution of Digital Literacy

Digital literacy is one of the most critical and much-discussed terms in contemporary educational theory. It was initially viewed as a set of technical skills, mainly related to the use of computers and basic software (Gilster, 1997). However, the rapid development of the internet, social networks and digital technologies has radically reshaped its concept.

According to Livingstone (2012), digital literacy is a complex set of competencies that includes accessing, analyzing, producing and critically evaluating digital content. UNESCO (2018) adds that digital literacy includes skills for participating in digital communities, understanding security, protecting personal data and responsible online behavior.

Contemporary literature has shifted from the traditional technical definition to a more critical and sociocultural orientation (Lankshear & Knobel, 2015), where technology is considered a tool for social participation, creativity and empowerment. The European DigCompEdu framework (Redecker, 2017) reaffirms this broadening, emphasizing that digital literacy includes not only skills, but also knowledge, attitudes and values necessary for participation in the digital society.

Jenkins et al. (2016) underline the role of participatory culture in the digital age, where users are called to become content creators and not simple consumers. Finally, Krumsvik (2014) proposes a pedagogical model of digital literacy that recognizes the importance of the didactic utilization of technology, enhancing independent, creative and collaborative learning.

2.2 Digital Skills and Learning in the 21st Century

The discussion around 21st century skills is inextricably linked to technology, creativity, collaboration and problem-solving (Voogt & Roblin, 2012). In contemporary educational discourse, digital literacy is recognised as a foundation for the development of critical life skills, such as information literacy, critical literacy, audiovisual literacy and responsible online behaviour (OECD, 2019).

Erstad and Voogt (2018) emphasise that, despite the general perception that students are “digital natives”, this does not imply that they have developed high-level digital skills. In contrast, many studies show that students may frequently use technology but lack the ability to assess the reliability of sources, engage safely online, or use digital tools for the benefit of learning (Hargittai, 2010; Hatlevik & Christophersen, 2013).

In Greece, Komis (2015) and Tzimogiannis (2020) argue that the digital transformation of education has accelerated in recent years, with the development of digital platforms, open educational resources, and blended learning. However, students often exhibit uneven levels of digital proficiency, as familiarity with technology is influenced by factors such as socioeconomic status, access to equipment, and support from the school environment (OECD, 2021).

2.3 The Role of School and Educational Policy

Schools are key actors in fostering digital literacy, through curricula, teaching practices and institutional support. According to Tondeur et al. (2017), the effective integration of technology depends on three main axes:

1. Pedagogical approaches of teachers,
2. Technological infrastructure,
3. School leadership and administration.

Pettersson (2018) highlights that the success of digital innovation requires coordinated policies that promote a coherent digital ecosystem within the school. This includes appropriate infrastructure, continuous training, clear targeting and collaborative processes.

In Greece, studies show that the degree of digital integration varies significantly between school units (Athanasoulas, 2019). Researchers such as Doukakis and Sampanis (2021) demonstrate that school leaders often lack the necessary training to guide digital reforms, resulting in fragmented actions without an overall vision.

2.4 The Teacher as a Determinant Factor

Although technology provides opportunities, the success of integration depends primarily on the teacher (Ertmer & Ottenbreit-Leftwich, 2010). The obstacles faced by teachers are divided into:

- First-order obstacles: logistical infrastructure, lack of time, technical support.
- Second-order obstacles: attitudes, self-confidence, pedagogical perceptions, knowledge of teaching models.

Tondeur et al. (2017) point out that teacher confidence is a determining factor for the effective use of digital tools. Research shows that many teachers feel prepared in basic skills but not sufficient for more complex digital practices, such as critically evaluating sources or guiding students in collaborative digital activities (Tzavara & Komis, 2020).

At the same time, professional development must be continuous and focused on the real needs of the classroom. Redecker (2017) suggests training models that include internships, reflection, mentoring and sharing of good practices.

2.5 Infrastructure, Digital Inequalities and Challenges

Infrastructure remains crucial for digital education. According to OECD (2021), inequality in access to digital media directly affects students' educational success. Schools with inadequate equipment are unable to implement modern pedagogical practices, such as blended learning, collaborative digital projects or creative digital production (Hatlevik & Christophersen, 2013).

The findings of this survey, where a large proportion of teachers stated neutral or negative views on the adequacy of infrastructure, are in line with studies showing that logistical support is a critical but often underestimated factor (Falloon, 2020).

Furthermore, the digital divide remains a significant problem, not only in terms of access but also in terms of the ability to exploit (van Dijk, 2020). Even when there is access to devices, the lack of digital capital – that is, strategies, know-how and support – limits learning development.

3. MAIN FOCUS OF THE CHAPTER

3.1 Issues, Controversies, Problems

The integration of digital literacy in schools is a complex process, accompanied by various issues, controversies and problems that affect its effective implementation. Although most educational policies emphasize the importance of technological integration in the classroom, reality often shows inconsistency between strategic goals and everyday teaching practice. Lack of technological equipment, unequal access of students to digital media and insufficient training of teachers create obstacles that limit the full use of school initiatives.

At the same time, there are controversies regarding whether the emphasis should be placed on students' technical skills or on more complex forms of digital competence, such as critical thinking, online safety and information management. Some educational approaches are still limited to the basic use of tools (e.g. office software), while others promote holistic models of digital literacy.

At the level of educational policy, the conflict between the theoretical value of digital initiatives and their practical implementation often arises. While official curricula include extensive references to the use of technology, teachers often report a lack of guidance, support or logistical resources.

A typical example of a relevant debate concerns the role of the teacher, “Is the teacher mainly a technical facilitator?”, “Or does he remain a pedagogical guide who uses technology as a learning tool?”

The different answers also lead to different school practices.

3.2 More Issues, Controversies, Problems

An additional set of problems is linked to school culture and internal organisation. Even when digital infrastructures are in place, a lack of collaboration between teachers or a lack of vision from management can hold back progress. “Digital innovation” in schools often depends on a few active teachers, which creates inequalities and inconsistencies in practices within the same school.

Problems also arise from the diversity of the student population. The existence of students with different digital experiences leads to variations that teachers find difficult to manage without additional support or training.

There is also controversy about the impact of digital media on the learning process. Some researchers argue that technology increases collaborative and exploratory learning, while others report that its excessive or uncontrolled use can lead to distraction or superficial learning.

3.3 Even More Issues, Controversies, Problems

In addition to the above, new challenges are constantly emerging due to the speed at which technology evolves. Schools are often unable to keep up with this pace, resulting in a time lag between what social and work conditions require and what education offers.

Concerns also exist around:

- the protection of students’ personal data,
- the ethical dimension of the use of digital tools,
- the dependence of students on devices,
- ensuring the quality of digital material.

These discussions make it clear that digital literacy is not only a matter of technological proficiency, but also of pedagogical and social responsibility.

4. METHODOLOGY

The methodology of this research was designed to systematically and scientifically investigate teachers’ perceptions of students’ digital literacy and the role of school initiatives in supporting it. The choice of a quantitative research approach was deemed appropriate due to the need to collect comparable data from a relatively large sample of participants, as emphasized by Creswell & Creswell (2018) in studies focusing on educational attitudes and behaviors.

The methodological approach includes four main parts: the definition of the sample, the selection and structuring of the research tool, the data collection process and the methods of their analysis. A detailed presentation follows.

4.1 Sample and Population

The research was conducted on a sample of approximately 50 teachers from primary and secondary education. The population they represent concerns teachers working in schools where digital actions, educational technology programs or technologically enhanced courses are implemented.

The selection of the sample was not random; purposive sampling was applied, appropriate when the interest of the research is focused on specific groups with special characteristics (Palinkas et al., 2015). Digital literacy is closely linked to the professional experience and attitudes of teachers; therefore it was deemed necessary to participate in individuals with proven involvement in school digital actions.

4.2 Sample Diversity and Heterogeneity

The composition of the sample was heterogeneous in terms of:

- teacher specialty,
- years of teaching experience,
- familiarity with technology,
- type of school (urban, suburban, rural),
- level of education.

This heterogeneity enhances the external validity of the research, as it contributes to capturing a multidimensional picture of digital literacy (McMillan & Schumacher, 2014). At the same time, the sample size is sufficient for descriptive statistics and comparative analyses in small-scale quantitative surveys (Bryman, 2016).

4.3 Ethical Safeguards

Participation was voluntary, with full anonymity and informed consent. The process followed the ethical guidelines of the British Educational Research Association (BERA, 2018), ensuring data protection and confidentiality of responses.

4.4 Research Tool

The data collection tool was a structured questionnaire, which is considered particularly effective for research that seeks to measure attitudes, perceptions and experiences of many participants (Cohen, Manion, & Morrison, 2018).

4.5 Justification for the Choice of Questionnaire

The use of a questionnaire is documented by the literature as being suitable for investigating topics such as:

- students' digital literacy (Redecker, 2017),
- teachers' attitudes towards technology (Tondeur et al., 2017),
- the evaluation of school digital initiatives (Falloon, 2020).

Its quantitative format allows for statistical processing and the identification of patterns in the data.

4.6 Questionnaire Structure

The questionnaire included four sections:

1. Demographics

Gender, age, specialty, years of service, level of education.

2. Attitudes and Perceptions about Digital Literacy

Likert scales 1–5 for familiarity, importance, difficulty of teaching digital skills.

3. School Initiatives and Support

Questions that assess technological infrastructure, training programs, and administrative support.

4. Student Digital Skills

Assessment of perceived skill levels, such as information search, critical content evaluation, collaboration in digital environments.

4.7 Question Types

- Closed multiple-choice questions.
- Likert scales, which are considered reliable for quantitative measurement of attitudes (Joshi et al., 2015).
- Open-ended questions, for qualitative nuances (Braun & Clarke, 2006).

4.8 Data Collection Process

Data collection was implemented via an online form (Google Forms), an option that is appropriate for questionnaire surveys with teachers due to ease of access and increased response (Dillman, Smyth, & Christian, 2014).

The process included the following steps:

1. Contacting schools and informing them about the purpose of the research.
2. Sending an electronic link to the questionnaire.
3. Duration of data collection: 10 days.
4. Reminders to participate without pressure or obligation.
5. Confirmation of voluntary participation and data protection.

The electronic format allowed for rapid and accurate transfer of data to Excel, reducing recording errors (Rumsey, 2020).

4.9 Data Analysis Methods

Data analysis was carried out with Microsoft Excel software, which is one of the most widely used tools for basic statistical processing and visualization (Knafllic, 2015).

Coding and Data Preparation

After extracting the responses:

- The data were entered into an Excel spreadsheet.
- The Likert scales were numerically coded (1–5).
- Any missing responses were checked (Field, 2018).

5. RESULTS

5.1 Question 5. Students Need Systematic Support for Developing Digital Skills

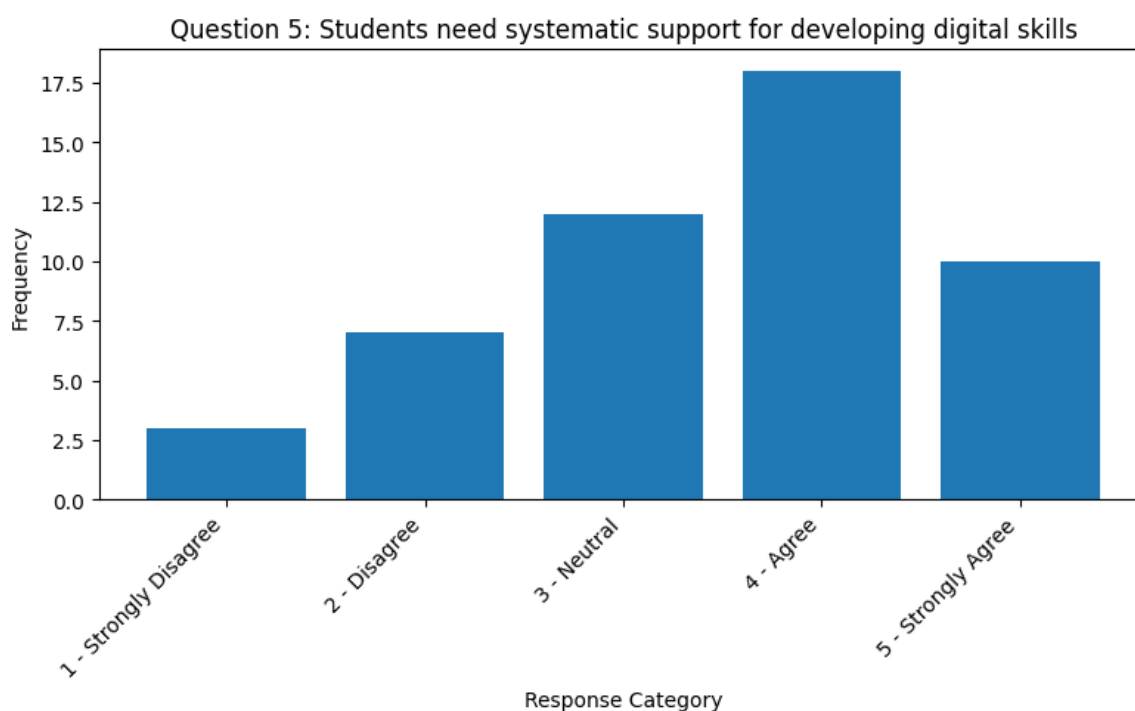


Figure 1. Responses to Question 5: Students need systematic support for developing digital skills.
Source: Research dataset, 2025.

Analysis

The distribution of responses indicates a strong tendency among teachers to agree that students require structured and continuous support to enhance their digital skills. The majority of participants selected Agree ($n = 18$) or Strongly Agree ($n = 10$), together representing 56% of the total sample. This suggests that more than half of the teachers perceive digital literacy development as a crucial and ongoing need in contemporary schooling.

A smaller portion of participants expressed neutrality (24%), indicating that some teachers may be uncertain about the extent of support students need or may lack direct experience with digital literacy initiatives. Only 20% of teachers disagreed or strongly disagreed, reflecting a relatively low level of opposition to the idea.

Overall, the findings highlight a widespread recognition of the importance of systematic, school-supported digital literacy instruction, aligning with international frameworks that emphasize digital competence as a foundational 21st-century skill.

5.2 Question 6. I Feel Adequately Prepared to Teach Digital Literacy

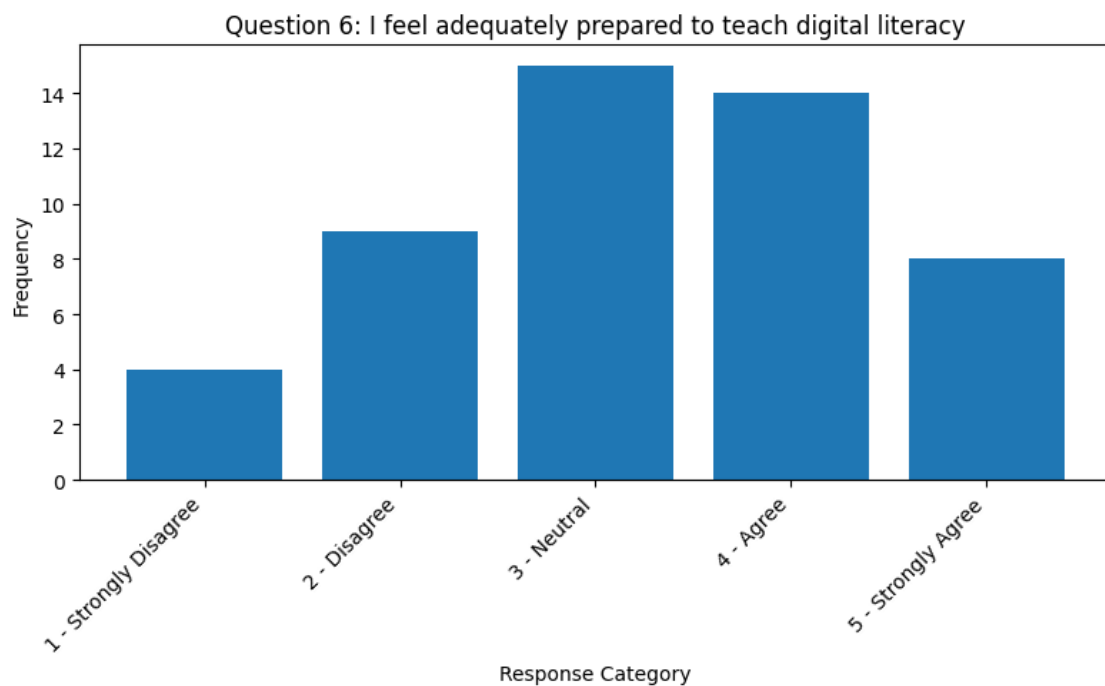


Figure 2. Responses to Question 6: I feel adequately prepared to teach digital literacy.
Source: Research dataset, 2025.

Analysis

The distribution of responses for Question 6 reveals a more varied perspective among teachers regarding their preparedness to teach digital literacy. The highest proportion of participants selected Neutral ($n = 15$), indicating significant uncertainty or mixed experiences with teaching digital skills. This neutrality suggests that while teachers may recognize the importance of digital literacy, they may not feel fully confident in their own training or pedagogical readiness.

A considerable number of teachers expressed agreement (n = 14) or strong agreement (n = 8), representing 44% of the respondents. This indicates that nearly half of the sample feels well-prepared, highlighting positive experiences with training, self-study, or practical exposure to digital tools.

However, 26% of the teachers disagreed or strongly disagreed with feeling adequately prepared, reflecting a persistent gap in professional development opportunities. These findings align with international research reporting that many teachers feel underprepared to integrate digital literacy into instruction without systematic training and institutional support.

Overall, the results suggest that while a substantial portion of educators feels reasonably confident, there remains a significant need for ongoing professional development to ensure consistent competence across the teaching workforce.

5.3 Question 7. Digital Literacy Is an Essential 21st-Century Skill

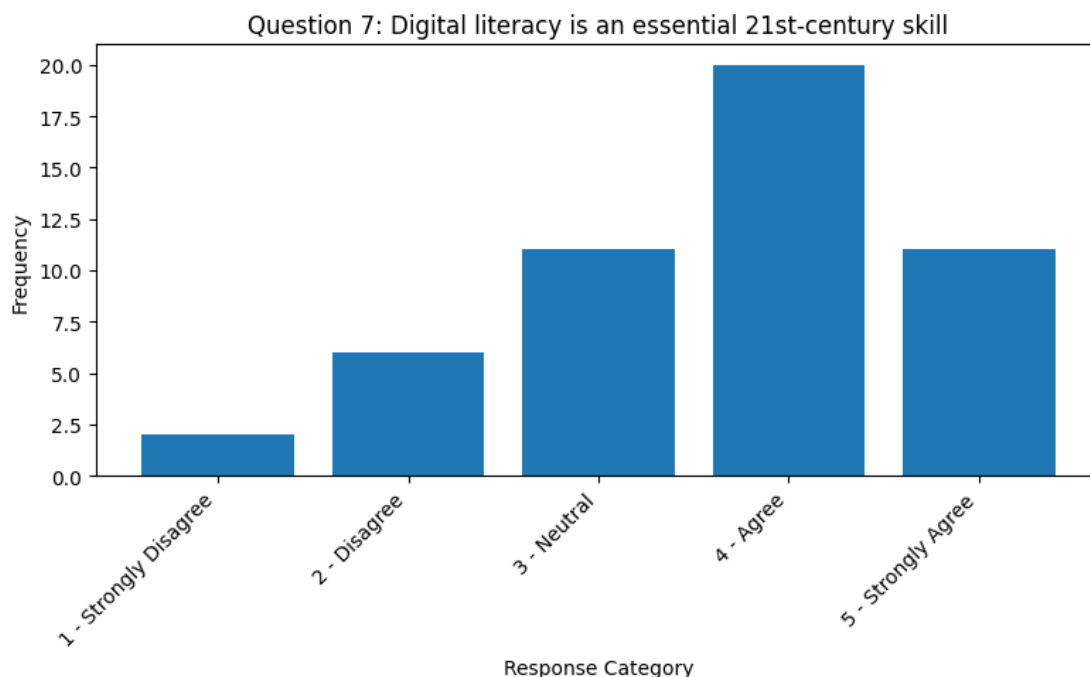


Figure 3. Responses to Question 7: Digital literacy is an essential 21st-century skill.
Source: Research dataset, 2025.

Analysis

The responses to Question 7 demonstrate strong consensus among teachers regarding the importance of digital literacy in contemporary education. The large majority of participants selected Agree (n = 20) or Strongly Agree (n = 11), representing 62% of all responses. This substantial agreement suggests that teachers widely recognize digital literacy as a fundamental competence necessary for students' academic development and future employability.

A moderate proportion of respondents (n = 11) expressed neutrality. This group may include educators who accept the concept in theory but do not yet observe sufficient practical alignment within their schools, or who feel uncertain about how digital literacy should be defined and operationalized.

Dissenting responses were very limited (only $n = 8$ combined for “Disagree” and “Strongly Disagree”), indicating minimal opposition to the idea. Such low disagreement highlights that the educational community is generally aligned with global frameworks emphasizing digital competence as a key 21st-century skill (e.g., EU DigComp, UNESCO ICT-CFT).

Collectively, the data indicate that teachers overwhelmingly acknowledge the importance of integrating digital literacy into the curriculum and view it as a central educational priority. This finding reinforces the need for institutional policies and training programs that match the high value educators place on digital literacy.

5.4 Question 8. Technology Enhances the Educational Process

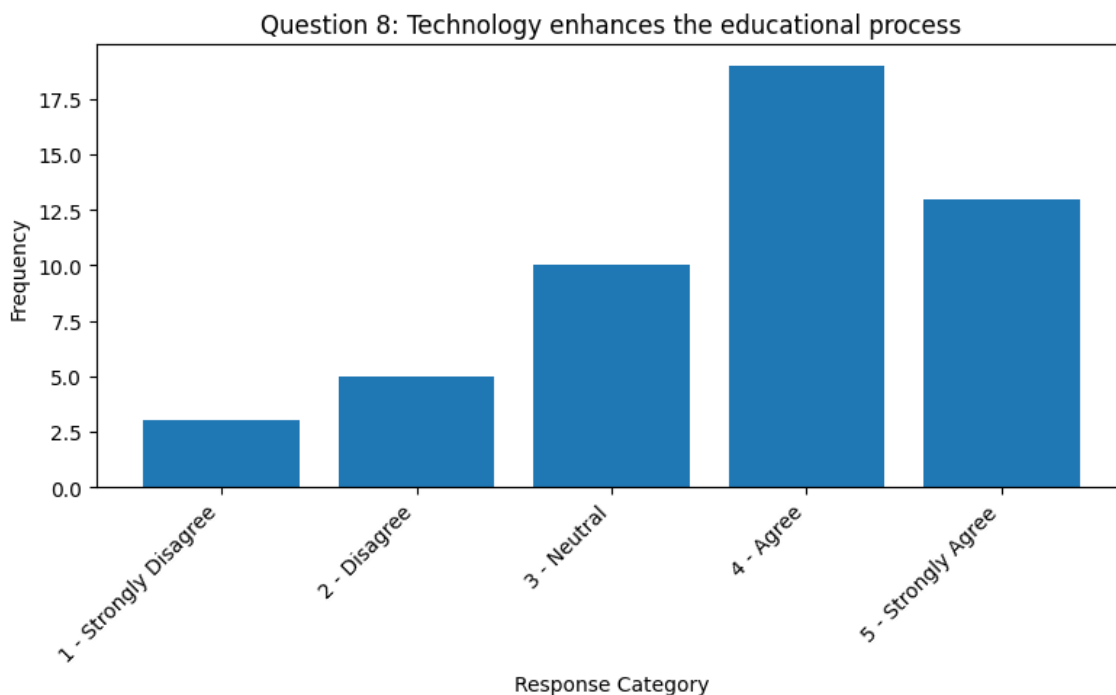


Figure 4. Responses to Question 8: Technology enhances the educational process.
Source: Research dataset, 2025.

Analysis

The responses to Question 8 reveal a strong positive perception among teachers regarding the role of technology in education. The majority selected Agree ($n = 19$) or Strongly Agree ($n = 13$), together representing 64% of the sample. This substantial majority suggests that teachers view technology as a valuable pedagogical asset that can support instructional effectiveness, student engagement, and differentiated learning.

A smaller but notable portion of respondents ($n = 10$) expressed neutrality. This group may reflect educators who acknowledge potential benefits but remain cautious due to challenges such as insufficient training, unreliable infrastructure, or limited integration within their school’s curriculum. Such neutrality is common in contexts where technological innovation is unevenly supported or inconsistently implemented.

Only 16% of the participants reported disagreement or strong disagreement. These responses may stem from concerns about student distraction, lack of time for teachers to adapt lessons, or skepticism regarding technology’s impact on deeper learning outcomes.

Overall, the results emphasize that, for most teachers, technology is not merely an optional enhancement but a meaningful contributor to improved educational processes. This aligns with international research highlighting the role of digital tools in fostering active learning, collaboration, and multimodal engagement.

5.5 Question 9. The School Has Adequate Digital Infrastructure

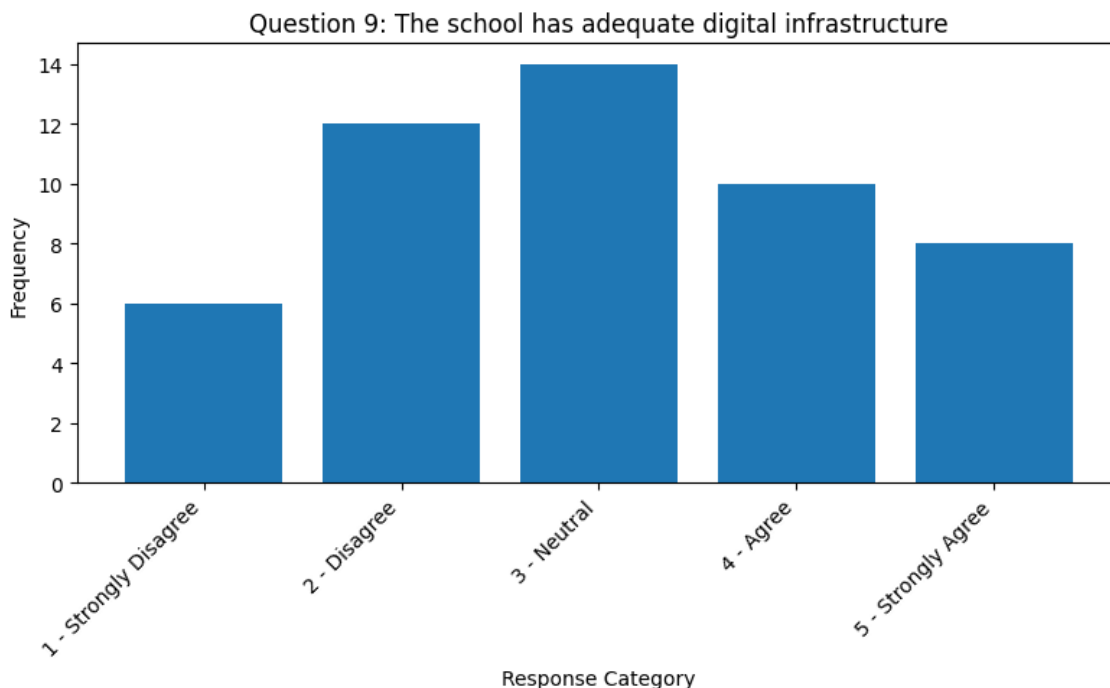


Figure 5. Responses to Question 9: The school has adequate digital infrastructure. Source: Research dataset, 2025.

Analysis

The results for Question 9 reveal significant uncertainty and concern among teachers regarding the adequacy of their school’s digital infrastructure. The highest number of responses fell under Neutral ($n = 14$), suggesting that many teachers experience inconsistent access to technology—neither fully sufficient nor entirely lacking. This ambivalence may reflect disparities in device availability, connectivity issues, or inconsistent maintenance of equipment.

A notable proportion of respondents expressed dissatisfaction:

- Disagree ($n = 12$)
- Strongly Disagree ($n = 6$)

Together, these categories represent 36% of all responses, indicating that more than one-third of teachers do not perceive the digital infrastructure as adequate. This level of disagreement highlights systemic gaps in technological provisioning, which aligns with previous research showing that insufficient infrastructure is a major barrier to effective digital literacy development.

Conversely, 18 teachers agreed or strongly agreed that infrastructure is adequate, representing 36% of respondents. This suggests that some schools have invested significantly in digital resources, but such improvements may not be uniformly distributed across all educational contexts.

Overall, the results reveal a mixed and uneven landscape, underscoring the need for targeted investment, more consistent technological upgrades, and ongoing support to ensure that all schools can fully implement digital literacy initiatives.

5.6 Question 10. School Initiatives for Digital Literacy Are Effective

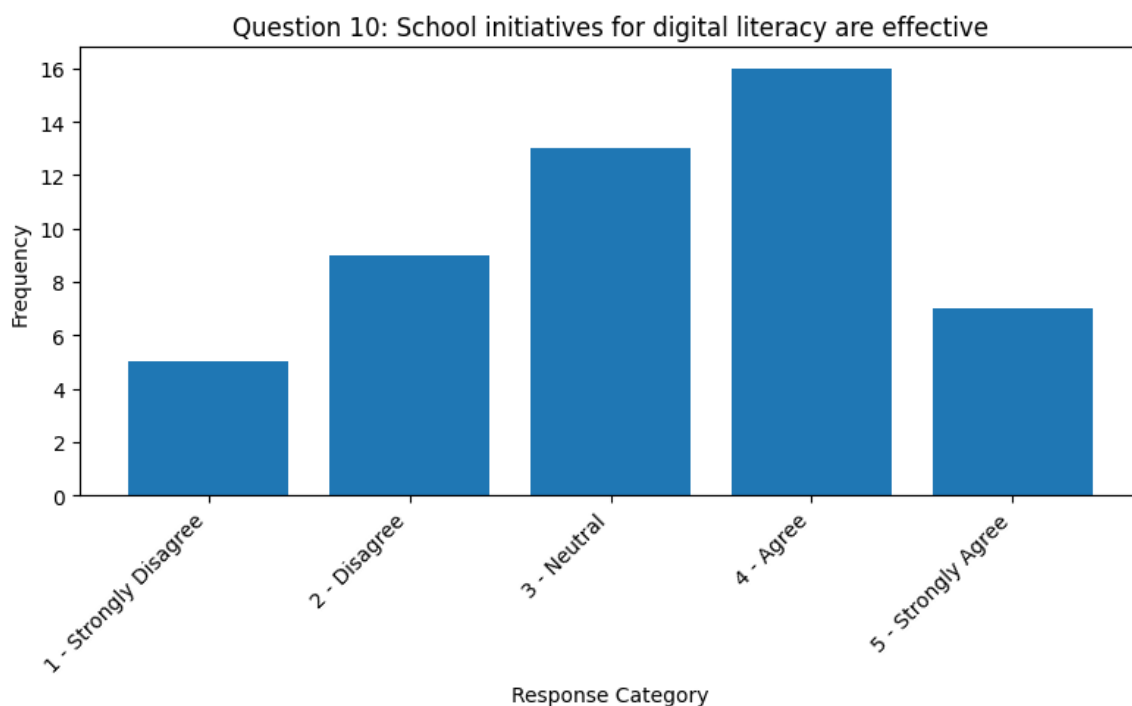


Figure 6. Responses to Question 10: School initiatives for digital literacy are effective. Source: Research dataset, 2025.

Analysis

The responses to Question 10 reveal a moderately positive perception of the effectiveness of school-based digital literacy initiatives. The largest proportion of participants selected Agree ($n = 16$), suggesting that many teachers see clear benefits and observable progress arising from the programs implemented in their schools. Additionally, Strongly Agree ($n = 7$) responses further indicate that a segment of teachers views these initiatives as highly successful.

However, the comparatively large number of Neutral responses ($n = 13$) indicates that many teachers may be uncertain about the actual impact of these initiatives. This uncertainty could stem from limited evaluation mechanisms, uneven implementation across classrooms, or insufficient communication regarding the goals and outcomes of digital literacy programs.

A notable percentage of participants expressed disagreement ($n = 9$) or strong disagreement ($n = 5$). These responses highlight ongoing challenges, such as inadequate training, lack of sustained administrative support, or insufficient alignment between initiatives and everyday teaching practice. Such

perspectives are consistent with research suggesting that digital literacy initiatives require continuous professional development and robust infrastructure to be effective.

Overall, the findings suggest that while many teachers perceive school initiatives as beneficial, there remains significant room for improvement, particularly in ensuring consistent implementation, providing clearer guidance, and strengthening evaluation processes.

5.7 Question 11. There Are Sufficient Training Opportunities for Educational Technology

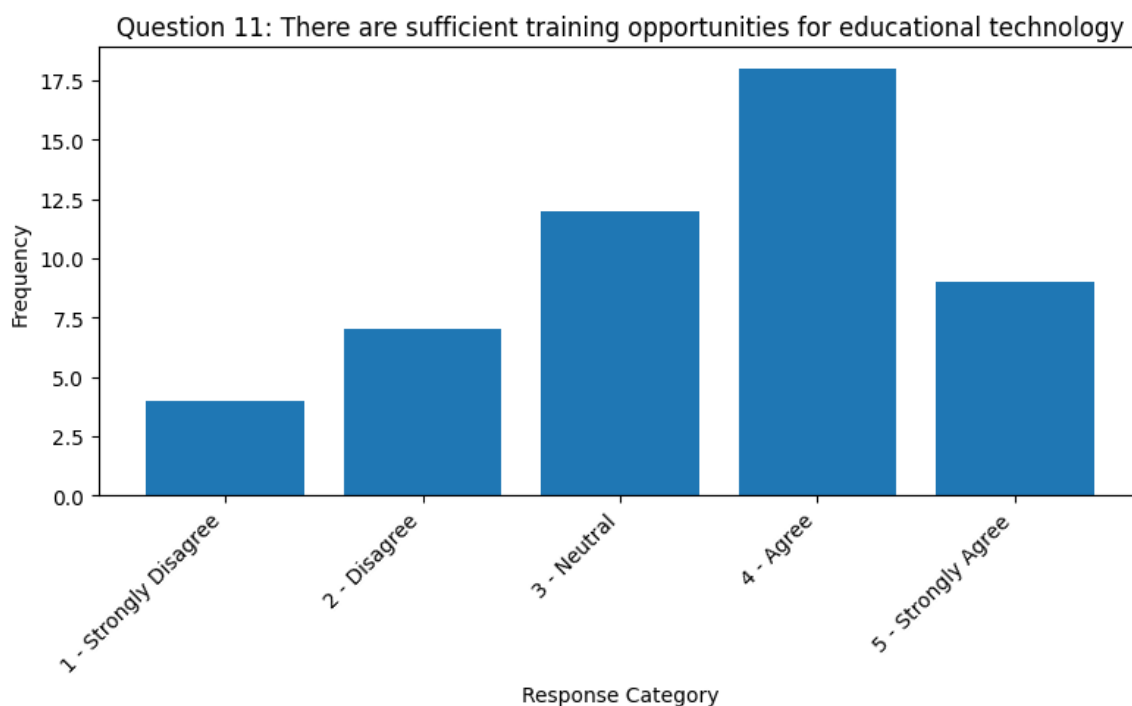


Figure 7. Responses to Question 11: There are sufficient training opportunities for educational technology. Source: Research dataset, 2025.

Analysis

The results for Question 11 reveal that most teachers perceive the availability of training opportunities in educational technology as generally adequate. The highest frequency of responses was Agree ($n = 18$), followed by Strongly Agree ($n = 9$). Together, these categories constitute 54% of the sample, indicating that over half of the teachers feel that sufficient professional development opportunities are provided within their school or educational environment.

However, Neutral responses ($n = 12$) represent a substantial portion of the dataset. This neutrality suggests that, for some teachers, training opportunities may exist but may not be easily accessible, frequent enough, or tailored to their specific needs. Teachers who selected “Neutral” may also come from schools where training is inconsistently offered or lacking formal structure.

On the other side of the spectrum, Disagree ($n = 7$) and Strongly Disagree ($n = 4$) responses highlight a minority of teachers who believe that current training provisions are insufficient. This result underscores a persistent gap: not all educators receive equal access to ongoing, high-quality professional development in technology integration.

Overall, the findings point to a moderately positive perception of available training but also signal the need for more systematically, equitable, and targeted professional development. Ensuring that all teachers—regardless of school context or experience—receive adequate support remains a key priority for strengthening digital literacy initiatives.

5.8. Question 12. School Leadership Actively Supports Digital Innovation

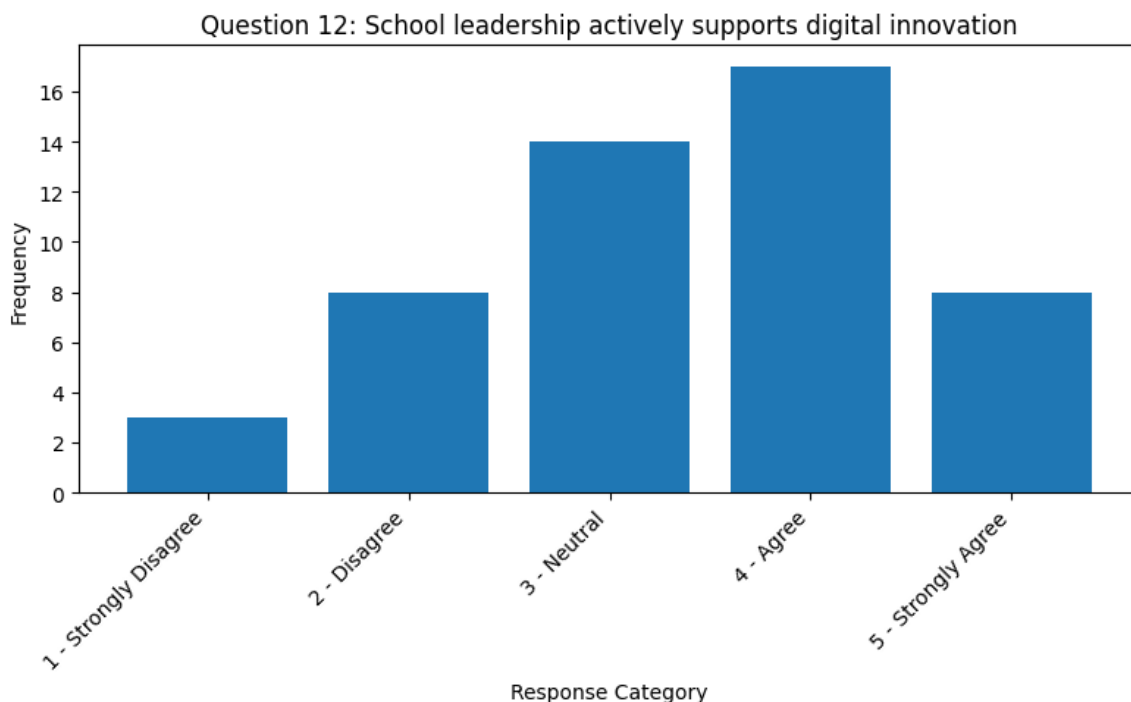


Figure 8. Responses to Question 12: School leadership actively supports digital innovation. Source: Research dataset, 2025.

Analysis

The responses to Question 12 reveal a predominantly positive perception of school leadership in relation to digital innovation. The largest proportion of participants selected Agree ($n = 17$), indicating that many teachers perceive their school administration as supportive of technological advancement and digital initiatives. Additionally, Strongly Agree ($n = 8$) responses reinforce this trend, with a combined total of 50% expressing confidence in leadership support.

Despite this overall positive sentiment, a significant portion of respondents ($n = 14$) chose Neutral, suggesting that the level of leadership support may not be consistently visible or equally experienced by all teachers. This neutrality may indicate a lack of clear communication about digital strategies, inconsistent implementation, or differences in how support is perceived across departments or grade levels.

Those expressing disagreement ($n = 8$) or strong disagreement ($n = 3$) represent a smaller but meaningful minority. Their responses highlight that digital innovation may still face internal barriers such as limited administrative involvement, insufficient long-term planning, or inadequate prioritization of technology-related initiatives.

Overall, the results show that while many teachers view leadership support as active and positive, there is substantial variability in perceptions. This suggests a need for more transparent communication, shared vision-building, and consistent administrative engagement to ensure that digital innovation is embraced as a whole-school effort rather than varying by teacher or department.

6. SOLUTIONS AND RECOMMENDATIONS

In this chapter, the findings of the study are interpreted and translated into concrete solutions and recommendations for schools, teachers, and policy makers. The proposed actions are discussed in relation to previous empirical research on digital literacy, school innovation, and technology integration.

6.1 Developing a Whole-School Digital Literacy Strategy

The results showed strong agreement that digital literacy is an essential 21st-century skill and that technology enhances the educational process (Questions 7 and 8). Teachers also agreed that students need systematic support to develop digital skills (Question 5). Taken together, these findings suggest that teachers recognise digital literacy as a core educational priority rather than an optional add-on.

However, the responses regarding school initiatives and their effectiveness were more moderate (Question 10), and many teachers remained neutral about the impact of these initiatives. This indicates a gap between teachers' high awareness of the importance of digital literacy and the perceived coherence and visibility of school-level planning.

Similar patterns have been reported in international studies, where schools adopt isolated projects rather than a comprehensive digital strategy (Falloon, 2020; Pettersson, 2018). Research on school innovation emphasises that effective digital transformation requires a whole-school vision, shared goals, and alignment between leadership, curriculum, infrastructure, and professional development (Voogt et al., 2013).

Recommendation:

Schools should formulate a written digital literacy strategy that:

- articulates a clear vision for students' digital competences, aligned with frameworks such as Dig-Comp;
- defines specific, measurable objectives for each grade level;
- clarifies roles and responsibilities of school leadership, teachers, and support staff;
- includes a realistic implementation timeline and evaluation plan.

Such a strategy can help transform fragmented actions into a coherent, sustainable approach.

6.2 Enhancing Digital Infrastructure and Equitable Access

Responses to Question 9 indicated a **mixed perception of digital infrastructure**: a considerable proportion of teachers either disagreed or remained neutral about the adequacy of equipment and connectivity. This echoes previous research showing that insufficient or uneven access to devices and internet connections remains a major barrier to meaningful technology use in schools (Livingstone, 2012; Krumsvik, 2014).

When infrastructure is unreliable, teachers tend to revert to traditional methods, even if they personally value digital tools. The study's findings therefore confirm that digital literacy cannot be developed consistently if basic infrastructural conditions are not guaranteed.

Recommendations

Ensure minimum standards of equipment (e.g., a sufficient ratio of devices per student, functional interactive whiteboards, stable Wi-Fi in all classrooms). Establish a technical support system (technician or trained staff member) to minimise downtime and reduce teachers' frustration with malfunctioning equipment. Promote equitable access by providing school-based devices or loan schemes for students who lack technology at home, in line with concerns about digital divides reported in earlier studies (Livingstone, 2012). Investments in infrastructure should be explicitly linked to the school's digital literacy strategy, rather than treated as separate, purely technical upgrades.

6.3 Systematic and Needs-Based Teacher Professional Development

The findings revealed a nuanced picture regarding teachers' preparedness: while many respondents agreed that they feel adequately prepared to teach digital literacy (Question 6), a significant proportion chose neutral or negative responses. At the same time, perceptions of training opportunities in educational technology (Question 11) were moderately positive but not unanimous.

This pattern is consistent with studies showing that teachers' self-efficacy for technology integration often lags behind policy expectations and that generic ICT training is not sufficient (Ertmer & Ottenbreit-Leftwich, 2010; Tondeur et al., 2017). Research underlines the importance of ongoing, practice-oriented professional development focused on pedagogy rather than tools alone (Redecker, 2017).

Recommendations:

- Design continuous professional development programmes that:
 - are based on a needs analysis of teachers' current competences and concerns.
 - include hands-on workshops where teachers design and test actual lessons.
 - offer follow-up coaching or peer support, not just one-off seminars.
- Encourage professional learning communities where teachers share lesson plans, materials, and experiences with digital literacy activities.
- Provide differentiated pathways (beginner, intermediate, advanced) so that training remains relevant for teachers at different levels of digital competence.

By aligning professional development with real classroom practice, schools can move teachers from neutral or hesitant positions towards stronger confidence in teaching digital literacy.

6.4 Embedding Digital Literacy Across the Curriculum

Teachers largely agreed that technology improves the educational process, yet the moderate ratings of the effectiveness of school initiatives suggest that digital activities may still be treated as add-ons instead of being integrated across subjects. International literature stresses that digital literacy is most effectively developed when embedded in authentic learning tasks across domains, such as problem-solving in science, collaborative writing in language classes, or data analysis in mathematics (Erstad & Voogt, 2018).

Recommendations:

- Integrate explicit digital literacy objectives into subject curricula, not only ICT lessons.
- Encourage teachers to design interdisciplinary projects (e.g., online research and presentation tasks, collaborative digital storytelling, media analysis activities).
- Provide curriculum guidelines and sample lesson plans that illustrate how digital tools can support specific learning outcomes.

Such integration can help ensure that all students have multiple opportunities to practise and advance their digital competences in meaningful contexts.

6.5 Fostering Students' Critical and Ethical Digital Practices

The questionnaire results (especially items on students' abilities to evaluate online information and collaborate digitally) indicated that while teachers recognise the importance of digital skills, they are not fully convinced that students already possess higher-order competences. This concern reflects broader research showing that young people's frequent use of technology does not automatically translate into critical, safe, and responsible digital practices (Livingstone, 2012).

Recommendations:

- Include targeted teaching activities on:
 - evaluating the credibility and bias of online sources.
 - understanding algorithms, privacy, and data protection.
 - respectful and responsible online communication.
 - managing screen time and digital wellbeing.
- Use scenario-based tasks and discussion of real-life cases (e.g., misinformation, cyberbullying) to link digital literacy with ethical and civic dimensions.

By moving beyond functional skills, schools can support students in becoming critical and responsible digital citizens, in line with contemporary frameworks for digital competence (Redecker, 2017).

6.6 Strengthening Leadership and Governance for Digital Innovation

The study found generally positive but not unanimous perceptions of school leadership support for digital innovation (Question 12). Research repeatedly emphasises that leadership plays a decisive role in sustaining digital transformation, by setting priorities, allocating resources, and modelling positive attitudes toward technology (Voogt et al., 2013; Pettersson, 2018).

Recommendations:

- Provide leadership training for principals and middle managers on digital change management.
- Establish digital leadership teams including administrators and teachers responsible for coordinating initiatives, monitoring progress, and ensuring communication.
- Recognise and support teacher leaders who pioneer innovative practices and can mentor colleagues.

When leadership is visibly engaged and informed, teachers are more likely to perceive digital initiatives as meaningful and sustainable.

7. FUTURE RESEARCH DIRECTIONS

Future research in the field of digital literacy and school initiatives must respond to the complexity of an ever-changing educational environment. Technological developments, new social needs and changes in students' learning profiles necessitate a more systematic and in-depth research approach. The findings of this study, which demonstrate positive attitudes of teachers towards digital literacy but also significant uncertainties around the adequacy of infrastructure and training, offer fertile ground for planning future research directions.

An important direction concerns the need for long-term and longitudinal research. The development of digital skills is a process that evolves gradually and is influenced by changing factors, such

as school culture, technological progress and students' personal experiences. Studies of this type can shed light on how students' skills and teachers' perceptions change over time (Erstad & Voogt, 2018) and explain whether school initiatives have a long-term pedagogical impact.

At the same time, the use of mixed methodological approaches could significantly enhance the depth and validity of research knowledge. The present study adopted a quantitative methodology, providing a broad picture of teachers' perceptions. However, issues such as pedagogical use of technology, digital confidence and school culture require a more qualitative investigation, through interviews, observations and analysis of teaching practices (Bryman, 2016). Such a combined methodology would provide a deeper understanding of teachers' and students' experiences, allowing for the emergence of hidden aspects that are not immediately visible through quantitative analyses.

Furthermore, comparative studies between different school environments can significantly contribute to strengthening research knowledge. As this research showed variations in perceptions of infrastructure and school initiatives, it is evident that the educational context influences the integration of technology. International literature confirms that factors such as socio-economic status, geographical location and school type influence the success of digital innovation (Pettersson, 2018; OECD, 2021). Comparative studies between urban, rural and semi-urban schools could reveal structural inequalities and lead to targeted policies that promote equity in digital education.

There is also a need for studies that focus on the evaluation of specific digital interventions. Despite the increasing integration of technology in education, few studies systematically examine the effectiveness of individual interventions, such as digital collaboration programs, learning applications, or training programs (Graham, 2019). Such a research approach would allow the development of evidence-based practices and provide clearer guidance to schools and teachers in designing effective digital actions. Another important area for future research concerns the active participation of students. This study focused on teachers' perceptions, which is a fundamental aspect of the educational process but leaves unexplored how students themselves experience digital literacy. According to Jenkins et al. (2016), students develop complex digital practices, which are not always reflected in adults' assessments. Future research could examine in more depth the experiences, perceptions and needs of students, in order to shape more participatory and child-centered education policies.

In addition, the role of school leadership emerges as pivotal and deserves further investigation. The findings of the present study showed that teachers have a positive — but not universal — image of the support they receive from school administration regarding digital innovation. Given that leadership is one of the most important success factors of digital reforms (Athanasoulas, 2019; Pettersson, 2018), future studies can explore the practices, perceptions and leadership styles that effectively enhance digital transformation. Such research would be useful both for the development of education policies and for the design of training programs for education executives.

Finally, rapid developments in artificial intelligence, machine learning, virtual reality environments, and learning analytics are creating a new generation of research challenges. Investigating the impact of these technologies on teaching and learning is now a necessity.

8. CONCLUSION

This study explored teachers' perceptions of students' digital literacy and the role of school initiatives in enhancing it, in a context of social, technological and educational transformations. Participating teachers universally acknowledged the importance of digital literacy as a key skill of the 21st century, confirming international findings that support the development of such skills as a crucial factor for students' participation in an increasingly digitalized society (Redecker, 2017; Erstad & Voogt, 2018).

This positive attitude suggests that teachers recognize digital literacy not as a complementary, but as a central dimension of modern education.

Despite the recognition of its importance, the findings revealed significant differences in perceptions of the quality and adequacy of school initiatives. While many teachers expressed satisfaction with the existing actions and training, a significant proportion were neutral or cautious. This heterogeneity reflects broader trends recorded in the literature, where the success of digital interventions depends on the existence of a coherent strategy, adequate resources and consistent leadership support (Pettersson, 2018; Tondeur et al., 2017). The research findings confirm that without a solid logistical infrastructure and systematic training, even the most ambitious initiatives risk having limited impact.

The data analysis also highlighted the complex challenges that schools face in expanding the pedagogical use of technology. Despite the existence of digital tools, their use often depends on teachers' pedagogical readiness and self-confidence, confirming Ertmer and Ottenbreit-Leftwich's (2010) position that internal barriers – attitudes, perceptions, levels of self-efficacy – are often more decisive than external ones. The presence of a significant number of neutral responses to questions about training adequacy and school leadership suggests that many teachers are experiencing a transitional period, where technology exists as an opportunity, but has not been fully and securely integrated into educational practice.

One of the most important conclusions of the study concerns the role of school leadership. The data showed that, while several teachers feel supported, others express doubts or uncertainty about the active contribution of the management in promoting digital innovation. International literature agrees that leadership is a foundation for sustainable technology integration (Athanasoulas, 2019; Pettersson, 2018). The lack of clear and consistent guidance can make it difficult to implement actions, reduce the cohesion of educational staff and intensify inequalities between school units. Equally important is the finding that, despite the frequent use of digital tools by students, many teachers doubt their ability to assess the reliability of information or to collaborate effectively in digital environments. This finding is consistent with research by Hargittai (2010) and Hatlevik & Christophersen (2013), which point out that familiarity with technology does not automatically imply true digital competence. The need for targeted teaching of critical thinking, digital ethics and responsible online behavior emerges as one of the most essential challenges of modern education.

Overall, the results of the study show that digital inclusion in schools is progressing, but not in a unified and balanced way. Teachers appear willing and positive towards the use of technology, but the success of their efforts depends on a series of interrelated factors: adequate infrastructure, continuous professional development, school leadership with vision and support, as well as coherent policies that promote equality in access to and use of technology. This research confirms that, despite the important steps that have been made, further systematic effort is required to achieve a comprehensive digital transformation in school education.

At a practical level, the findings indicate the need to develop integrated school strategies that will ensure the continuity and consistency of digital actions. Strengthening teacher training, consistent technical support and the use of new technologies as learning tools can be central points of intervention. In addition, systematic evaluation of digital actions and the involvement of students in the formulation of educational policies can enhance the sustainability and effectiveness of interventions.

Finally, the study demonstrates the need for further research, which will delve into the different aspects of digital literacy, uncover students' experiences, evaluate specific interventions and examine the impacts of new technologies on teaching and learning. The digital transformation of education is an ongoing process, and the research community is called upon to actively contribute, providing knowledge that will support the development of effective, equitable and future-proof school practices.

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KEY TERMS AND DEFINITIONS

- Blended Learning:** A structured educational approach that combines face-to-face instruction with online learning components, allowing students to engage with content both in person and digitally.
- Critical Digital Literacy:** The ability to analyze, evaluate, and interpret digital information and media, focusing on issues such as credibility, bias, authorship, and socio-political context.
- Digital Citizenship:** Responsible and ethical participation in digital environments, including safe communication, respectful interaction, and protection of personal data.
- Digital Competence:** A broad set of knowledge, skills, attitudes, and values that enable individuals to use digital tools effectively, critically, and responsibly in learning, work, and daily life.
- Digital Infrastructure:** The technological foundation of a school, including hardware, software, connectivity, and technical support systems necessary for digital learning.
- Digital Pedagogy:** The intentional use of technology to support instructional design, teaching strategies, and learning experiences within formal and informal educational contexts.
- Information Evaluation:** The process of assessing the credibility, relevance, accuracy, and reliability of online information sources.
- Professional Development:** Continuous training and learning opportunities designed to enhance educators' pedagogical and technological skills to improve instructional effectiveness.
- School Leadership:** Administrative and managerial practices within a school that guide decision-making, resource allocation, and strategic planning related to teaching, learning, and innovation.
- Technological Integration:** The incorporation of digital tools, platforms, and resources into the curriculum and classroom activities to enhance learning outcomes and engagement.

8. The contribution of digital technology to education

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Abstract: This chapter refers to digital technology and the way it impacts society and culture. It emphasizes its contribution to education, the development of students' digital skills, and the evolution of knowledge. Digital technology offers the new generation a multitude of opportunities, enabling it to meet the ever-increasing demands of our technologically driven era and at the same time redefining the educational process. With its application in the educational environment, education becomes digital. The objective of the chapter is to highlight the contribution of digital technology to education and the development of students' digital skills, as well as to promote its utilization by teachers in teaching. The chapter presents the importance of digital technology as an educational approach within the context of digital education. Also, it points out that digital education, thanks to digital technology, is improving and pushing teachers towards a broader development as well as encouraging students to promote their learning skills.

Keywords: digital technology, digital education, teachers

1. INTRODUCTION

This chapter addresses digital technology and the way it impacts society and culture. It also highlights its contribution to education, the development of students' digital skills, and the evolution of knowledge. Digital technology, with its wide range of tools, offers the new generation a multitude of opportunities, enabling it to meet the ever-increasing demands of our technologically driven era and at the same time redefining the educational process. With the application of digital technology in the educational environment, education becomes digital. The objective of the chapter is to highlight the contribution of digital technology to education and the development of students' digital skills, as well as to promote its utilization by teachers in teaching.

In the last decade, digital technology seems to have become the demand in the educational field. Several educational programs are based on the use of computers and there are many times when new technologies are integrated into educational activities and solve problems. The constant effort to implement technological developments in educational environments makes it more imperative to investigate the attitudes of teachers, who are central pillars for integrating digital technology into the educational process (Tondeur et al., 2008). When teachers apply digital technology in the educational process, they follow the modern requirements of digital society. The attitudes of the educational population are related to their teaching ideologies, their sense of self-efficacy, and the interaction they have with their student audience.

This chapter also focuses on the benefits and difficulties of digital education in educational units. Teachers often have a positive attitude towards digital technology and consider it important for the development and progress of the learning process. According to Koehler and Mishra (2009), many studies have showed the positive attitude that teachers have towards technology, which contributes to its successful integration into educational practice. In digital education, the role of the teacher changes, as he now helps and advises the student, enabling him to be more independent in learning.

The application of digital technology in the educational routine is directly related to the development of the student. The teacher, with the help of digital technology, creates the appropriate conditions so that the student can cultivate his digital skills. The student acquires digital skills related to the acquisition of abilities such as technological knowledge, critical thinking, the ability to solve problems, manage information, collaborate, create and communicate. With its help, the student does not passively receive knowledge but acquires an active role in controlling his own knowledge. By using an asynchronous communication environment, the student can, through interaction with other students and the teacher, be led to autonomous learning and the acquisition of new knowledge. An educational activity using digital technology can contribute to the creation of participatory learning. There, the student will be able to share his ideas and experiences, comment on the activities of others, plan and implement his goals and ideas, and become an active recipient of knowledge.

However, there are many cases of teachers expressing their reservations, gripped by feelings of low self-confidence, and insecurity during their interaction with digital technology. This fact acts as a brake on their efforts to implement digital technology to the extent they would like. Perhaps the cause of this behavior is lack of education and training in digital skills.

Also, an obstacle for the implementation of digital technology is the fact that infrastructure and necessary technological equipment are often absent from school grounds. A parameter that plays a decisive role in educational reality and influences the use of digital technology in the educational space can be considered insufficient state support and insufficient institutional incentives provided to educational units.

In general, in this chapter, the importance of digital technology as an educational approach and innovation tool for teachers within the framework of digital education is highlighted. It is also observed that digital technology encourages students to promote their learning successes and contributes to the development of their developmental activities. It is now clear that digital education with the contribution of digital technology aims at the broader development of all participants, teachers and students, and of the learning process itself. Finally, in this way, educational units develop and progress.

2. DIGITAL TECHNOLOGY

2.1 Digital technology and the social sector

The era we are living in presents a technological slant and is filled with a series of continuous technological achievements of the digital world. Many aspects of human activity have the imprint of technology. The emergence of the internet has redefined the way we work, communicate, learn and manage everyday life. Regarding the educational sector, technology has allowed teachers and students to develop personalized educational experiences and enhance collaboration and creativity.

Regarding the relationship between technology and society, one finds that the social dimension plays an important role, since digital tools cannot be understood without coexistence and interaction with humans. The new digital media have raised concerns that are intertwined with the nature of the society that promoted them and, by extension, with the type of educational unit that will be designed to harmonize with the framework of the new economic, social, cultural and technological reality. This leads one to the conclusion that not only is it necessary to place digital technology at the forefront of global, economic, social and cultural events, but the contribution of each local specificity is also required.

Digital technology is the totality of knowledge, methods, and systems that make use of digital data, such as codes and bits. It is the foundation and key part of the new technology that processes and transmits information in the form of audio, image and video (Koukoufiki, 2016). Digital technol-

ogy has emerged as a powerful tool that helps teaching methods evolve and the learning process be enhanced. The continuous progress of this technology has offered new possibilities to teachers and opportunities to improve their teaching practices, so that they can be harmonized with the demands of modern, rapidly changing society.

Digital technology as a pedagogical tool and means of communication influences educational design worldwide and focuses on its increasing integration into the learning process, modernizing 21st century schools. According to Koukoufiki (2016), integration is a complex process, which involves influencing the current educational policy, the curriculum, the available infrastructure, the institutional framework and funding, the skills of teachers and the receptivity of students.

Digital tools, such as interactive screens, computers, tablets, applications and media are being integrated into the classroom and are greatly influencing educational practice. Emphasis should be placed on providing an appropriate way to utilize them rather than simply installing the technology. The application of digital tools and media should be related to the existence of tools that contribute to the cultivation of skills, such as that of educational software and pedagogical environments whose purpose is to facilitate the education of teachers and students, through individual training programs.

2.2 Educational utilization of digital technology

In the modern era when technology is evolving at a rapid pace and has influenced many aspects of everyone's daily life, educational systems are faced with the challenge of changing their traditional structure and integrating digital technology into their programs. Digital technology is considered a learning tool or framework that contributes greatly to the improvement of the educational process. Teachers understand the importance of digital technology in the learning process and utilize it in their daily teaching practice.

Taking advantage of the possibilities offered by digital tools, such as personalized learning, enhanced participation and interaction, collaborative learning, educators create more dynamic, inclusive and effective learning environments and prepare the student population to meet the challenges of the modern era (Anastasopoulou et al., 2024). At the same time, teachers, by utilizing new technologies, enhance the learning process and promote students' creativity. With proper preparation, students will transition smoothly into the digital society and will be equipped with the necessary skills to advance successfully in their professional careers.

Regarding traditional teaching, teachers can utilize digital technology mainly as an additional tool, aiming to arouse students' interest and help them better understand certain aspects of the material being taught. Also, the use of digital technology as a simple auxiliary tool aims to improve traditional face-to-face teaching and facilitate the transmission of knowledge. In the most modern and creative form of teaching, digital technology is utilized as the environment that enhances teaching, making it more effective and at the same time encouraging students to actively participate in the educational process. In this case, students are not passive observers, but creative participants in the construction of knowledge.

It is worth noting that in an educational design, teachers can utilize digital technology not simply as a teaching tool, but as a framework for communication and knowledge transmission.

3. DIGITAL EDUCATION AND DIGITAL SKILLS

3.1 Digital education

Digital education lies in the use of digital technology during the learning process. It is an educational activity that uses digital tools, such as interactive screens, computers, tablets, applications, for

teaching, learning and assessment, making education more flexible, accessible and personalized and enabling teachers and students to develop the appropriate digital skills for the modern world. The use of digital technology contributes to the achievement of learning and can be used during general as well as special education.

The integration of digital education in the school environment can improve the atmosphere in a classroom and contribute to the learning progress of students thanks to the rich educational material it offers within the context of the lessons (Lavidas et al., 2022). Also, the implementation of digital education and digital tools within the classroom contributes to the cultivation of students' digital skills.

Digital education helps improve students' critical thinking and digital skills, as it combines image, sound, game, or interactive activity, with the aim of acquiring new knowledge (Naseem, 2021). Teachers must utilize more effective learning methods given their knowledge, digital or not, and the demands of their students. Digital technology is now becoming an integral part of the learning process, and every teacher would do well to promote the digitalization of education, as advanced technologies are making their appearance in their own lives and those of their students (Ross, 2020).

Regarding the quality of digital education, it lies in the appropriate design of the learning process and its implementation by the teacher. For educational planning to be effective, the existence of digital familiarity by the teaching and student staff and their ability to utilize new technology within the classroom must be considered.

There has been an increase in the number of teachers who choose to use digital knowledge and seek to impart digital skills to their students (Hampton et al., 2021). Also, many teachers show great interest in integrating digital education into their teaching. However, the percentage they constitute is not yet sufficient to meet the demands and needs of digital society.

3.2 Digital skills

Technology, with its rapid evolution, has contributed to changing every aspect of human life, as well as the way in which individuals communicate, gather information and acquire new knowledge. Thus, people's daily lives have been greatly affected, and this is also reflected in their educational practices. Teachers are faced with new challenges that contribute to redefining their pedagogical and teaching frameworks and are linked to issues related to the skills and knowledge of their students. Also, teachers must be helpful in transmitting knowledge in every way, to increasingly attract the interest of their student audience.

Digital technology and digital tools, which are applications that use this technology to automate processes, improve communication, process data and create new experiences, should be basic elements for teachers as they attract students' attention. Consequently, teachers' digital competence can become useful and essential for their ongoing professional development. However, many teachers feel wary of digital environments, as they are attached to adopting the traditional teaching model. At the same time, they are convinced that new technologies do not fit their work and they do not have the necessary knowledge to integrate their application into the educational process.

To be effective, education should enhance the digital skills of teachers and students, which refer to their ability to use digital technologies, IT tools and the internet in a safe, effective and critical manner for teaching, learning, communication and research. Also, teaching that aims to cultivate students' digital skills can empower students to be able to select reliable information to inform themselves, and to adopt ethical attitudes and values when interacting with digital environments.

According to Van Laar et al. (2017), there are seven key skills, the necessary digital skills of the 21st century: technological ability, information management, as well as skills such as communica-

tion, collaboration, creativity, critical thinking and problem solving. All these skills compose the set of fundamental acquired abilities of the individual required to be able to respond to a wide range of professions.

Technological ability refers to knowledge related to technology and digital media. Information management and communication is consistent with the ability of individuals to transmit information using digital media and applications. Communication and collaboration aim to promote interaction with colleagues in order to achieve common goals. Collaboration is about using new technologies to develop a social network when individuals work in groups. On the other hand, creativity when combined with the use of new technologies is related to the search for and creation of new goals and ideas. Critical thinking is related to the application of new technologies to make informed decisions following extensive argumentation, selection of necessary sources, and exchange of knowledge and opinions. Problem solving with the help of new technologies is about cognitive processing and understanding of a problematic situation when knowledge and digital resources actively contribute to achieving its solution.

4. THE ROLE OF TEACHING STAFF

The effective integration of digital technology in the educational space can be considered to depend on the attitudes and teaching ideologies of the educational population. Teachers as designers of pedagogical communication are central factors in activating and reshaping the opportunities that digital technology offers to students. Also, with the implementation of new technology and the latest digital media, the role of the teacher has changed, as he is given the opportunity to innovate in methods and actions and to offer novel teaching practices to the student population.

The teaching staff plays an important role in the integration of digital technology in the school environment, as they act as mediators between technology and the learning needs of the student community. The teacher is not limited to using only technological means but also must shape a supportive learning environment that is conducive to students' creativity, critical thinking, and self-regulation. He also faces challenges related to adapting to new educational practices, ensuring equal access for students to digital media, and managing issues related to the rational application of technology in teaching (Tytarenko et al., 2024).

Teachers' attitude towards new technology in the era we live in and towards the new curriculum also defines their decision regarding the integration of digital media into the learning process. Although some teachers may hold negative beliefs about the use of technology and digital tools, their attitude towards their integration into the school environment must be related to the approved curriculum and the needs of the student audience. Thus, it becomes understandable that despite some teachers not liking technology, they should apply it quite often in their teaching (Scherer et al., 2018) and their attitude towards it should not affect the integration of digital media in classrooms (Nelson et al., 2019).

However, there are teachers who are cautious about the application of digital technology in teaching. Some believe that close relationships with technology can lead to a deterioration of their interpersonal relationship with their students. Teachers' personal position towards technology also affects its application in the school environment.

The effective utilization of digital technology in the educational process requires appropriate training. According to Tytarenko et al. (2024), teachers who are open to innovations and participate in training programs apply digital technology more effectively and tend to create a more dynamic and modern learning environment.

According to Spiteri and Rundgren (2020), some teachers do not create digital educational materials, as they have limited digital skills, which affect their teaching. Teachers' digital skills are intertwined with a more general attitude that teachers adopt towards technology. Their digital skills should be cultivated and applied as educational tools that engage the student population.

Factors that influence teachers regarding new technologies and their application in the school unit relate to their familiarity with them, the available logistical infrastructure, their training and their pedagogical perceptions. Many educators are recognizing the importance of new technologies, such as virtual and augmented reality, adaptive learning platforms, and interactive media, as powerful tools that contribute to enhancing teaching and differentiating learning. Also, there are some teachers who support that in order to achieve a smooth integration of new technologies into the educational environment, time, adequate training and support from the current educational system are required.

There are factors that influence the educational process with the implementation of digital technology. Some of these are the existence of teachers' skills and knowledge, their personal views, the general school climate and the support from their superiors that teachers receive for exploiting novel technological opportunities. There is also the version that teachers are turning to digital technology because they want to attract the interest of the student population, a fact that is evident from their increased involvement in educational practice and the enthusiasm they feel during the lesson.

According to Kervin and Mantei (2009), the motivations that encourage teachers to integrate digital technology into the classroom are particularly important, as are the reasons that influence their implementation and relate to the educational methods practiced in teaching.

In conclusion, the application of new technology in the educational space, and digital technology in general, is the result of a dynamic process that is consistent with the ability of teachers to adapt to constantly changing educational methods. Beyond the challenges that arise, the professional development and fluency of teachers, with the help of training programs and supportive policies, is important because it strengthens the educational process. Digital tools can offer new opportunities for students to enhance their learning experience. However, for their successful implementation in educational practice, the existence of the right infrastructure and the willingness of teachers to engage in innovative learning methods play an important role. Teachers' attitudes become a critical factor in the successful integration of digital technology into the learning process. Also, their positive attitude towards new learning methods and their willingness to innovate contribute decisively to the correct use of digital tools. According to Kervin and Mantei (2009), as teachers understand technology as an important aid in their educational practice and perceive its benefit in enhancing learning, they are likely to adopt and use new teaching and learning methods.

5. BENEFITS OF IMPLEMENTING DIGITAL TECHNOLOGY IN EDUCATION

The integration of digital technology into the educational process is carried out indirectly through its pedagogical use. The interest of the student population in the application of computers as a learning tool and the existence of their active participation through interactive activities are key factors for their successful integration into the learning process (Moraiti, 2019). Beyond this, the effective pedagogical utilization of digital technology requires the existence of a comprehensive learning framework, which includes an integrated organization of teaching, learning activities and educational scenarios.

Technology, with its tools of expression, information search and knowledge visualization, strengthens the learning process. Students use new technologies that act as pedagogical tools that stimulate their development at a cognitive and investigative level. Technological approaches include software

that facilitates the expression, search and communication of information, as well as learning environments that contribute to enhancing discovery, exploration and knowledge construction. Thus, digital technology functions as a pedagogical tool that supports the cognitive and investigative side of teaching practice. At the same time, digital technology is considered as the cognitive tool that enhances the process of thinking, problem solving, learning, memorization and attentiveness. According to Moraiti (2019), students can organize and record their knowledge on specific learning subjects, with the help of technological applications.

The utilization of digital technology in the educational environment provides a multitude of benefits that determine the teaching process and learning practice. Specifically, digital technology acts to enhance differentiated teaching as it allows teaching staff to adapt their educational materials to the needs of the student population and offer novel learning methods. Digital technology creates a more tailored learning environment, disseminating knowledge in such a way as to enhance students' engagement in the educational process and to develop the skills required by the 21st century (Wijnen et al., 2023).

At the same time, technology acts to facilitate interaction and collaborative learning, enabling students to actively participate and build their knowledge through group activities and collaborative programs. The existence of digital forums, collaborative platforms and interactive software, which are digital tools, enhances interaction and communication skills among students (Wijnen et al., 2023).

In conclusion, the integration of digital technology into teaching practice offers the opportunity for continuous reassessment of the educational process, providing feedback from the students. In this way, areas for improvement are highlighted and teachers are given the opportunity to implement new practices. Feedback can be considered one of the most powerful factors that enhance learning performance.

6. DIFFICULTIES OF DIGITAL EDUCATION AND TEACHER TRAINING, EQUIPMENT AND INFRASTRUCTURE

6.1 Difficulties of digital education and teacher training

Despite the awareness of the usefulness of digital technology in the educational field, its utilization encounters several difficulties even today. The educational process, due to the challenges and obstacles it encounters, cannot easily meet the ever-increasing demands of the digital age. This fact does not relate to the scientific background of the educational population or the curricula, but concerns the weak digital skills of teachers, who do not express the digital vision of learning (Prieto-Ballester et al., 2021). The limited digital skills of some teachers to implement advanced technological tools, as well as their low self-confidence when using their digital skills with students, cause them to resist further adoption of digital technologies which reflects negatively on their student audience.

Teachers should realize that they must continuously improve their practices and methods with the addition of digital technology. The digitalization of the learning process requires teachers to invest in training programs, dedicating personal effort and time, to achieve optimum use of digital tools and technological environments (Scull et al., 2020). Regarding digital tools that can be used outside the classroom as asynchronous education to enrich the lesson with more educational material, teachers can use them to encourage the student population to communicate and collaborate with each other outside of school hours. In this way, students help their peers by providing them with feedback and distributing new ideas and suggestions regarding the content of the education.

Outside of online learning platforms that are often a personal choice, digital development can also be implemented with the collaboration of the educational staff, the administrative department and the

IT department of each school unit. Beyond the variety of education management systems and digital learning portals, the process of digitizing education is not yet complete. This transformation must be re-examined to meet all school needs and the needs of each teacher. Thus, education can make a transition to an enhanced digital form.

Rapid social development affects every sector, starting with the student population who, as tomorrow's future citizens, will enter the job market and live in the digital age. Therefore, they must harmonize with it and progress. The result of this development is the emergence of new challenges and the creation of possible uncertainties for the development path of the education system. Education should be governed by more relaxed rules and adopt several teaching options, in accordance with the curriculum. Both the teaching and student population will benefit from this improved teaching method, as the new digital skills that will need to exist in the future will now be an integral part of the daily learning process in the school unit. According to Alenezi (2021), technological developments have disrupted employment opportunities and modified qualifications and labor demand. Educators should maintain a friendly attitude towards technological development, the cultivation of digital skills, as well as the abilities that society demands of 21st century citizens. In this way, teachers will be able to fulfill their role as assistants to their students in preparing them for their later lives (Leonardi & Treem, 2020). But in addition to teachers and students being encouraged to engage in digital skills, for the digital vision of education to be realized, the necessary technological equipment must also exist.

6.2 Equipment and infrastructure

The difficulties faced by schools will continue to exist beyond the adoption of digital educational methods and the continuous use of new technology by teachers and students during the learning process. To transform traditional schools into digital ones, it is essential to equip them with the appropriate equipment. This will improve their pedagogical opportunities and the working practices of the educational staff. Therefore, the existence of the necessary infrastructure for the classroom to welcome technological development is of major importance. The existence of digital tools has become increasingly necessary. They are available for teachers and students at home (Ross, 2020), but the same is not true within the school environment. Therefore, it seems that in order for education to be digitized, school units and information systems need to have the appropriate technological infrastructure, so that they can address any technological problem that arises. When education is digitalized, students can easily cultivate their digital skills and navigate the internet safely. Thus, the school unit will be able to provide students with the opportunity to become digitally literate citizens.

The combination of digital media and their applications with educational materials is the guiding principle of the educational process that the teacher must implement within the context of an evolving digital society. For digital education to be effective, it is important for students to achieve their learning goals, understand the functions of digital media, and cultivate their digital skills. Thus, the digital media and educational content that the teacher will choose to give to his students are those elements that will help students broaden their knowledge.

Teachers, principals, and educational policymakers must create the appropriate opportunities through digital technology to improve conventional learning experiences in schools and cultivate digital skills. According to Kryukov and Gorin (2017), digital education can have a positive impact on students, preparing them to cope with the demands and needs of the 21st century. Therefore, every educational system should contribute to promoting and providing for the digitalization of school units.

7. CONCLUSION

Digital technology is being embraced as a tool that enhances teaching. Teachers, using digital tools and media, should better understand and visualize an appropriate teaching content. Teachers should utilize digital technology as part of their educational practice and as a database for the modern digital era. In this way, the school will be able to operate as efficiently as possible and fulfill its purpose, which is to help students with their digital training.

Digital technology is part of a broader socio-cultural happening. Teachers raise concerns about the unequal access of students to technology, the inequalities that are observed between school units, regarding the logistical infrastructure and the difficulty they themselves have in coping with the growing needs of digital skills without the existence of appropriate support. Several teachers do not utilize digital technology as a culturally and socially necessary tool. This fact confirms the need to strengthen the theoretical and practical training of teachers towards a more multi-level and reflective technological approach in the educational field. During their training, teachers should not be limited to technical skills in applying digital technology, but should critically cultivate its possibilities and limitations, as well as the social significance it brings.

To integrate digital education into the school environment, it is not enough to simply adopt digital technology, but to change the digital and educational culture of each school unit, each teacher individually, as well as the educational process itself. Also, it would be good to have the necessary digital equipment and appropriate infrastructure in each school unit. Therefore, digital education to take the form of a productive process, every classroom should have the necessary equipment to introduce digital technology into the learning process. At the same time, politicians should provide adequate infrastructure in schools with equal access to all, so that the whole student population can gain access to digital learning.

There are opportunities for digitalization of learning and development of digital teaching when innovative processes based on digital technological means are applied (Dhawan, 2020). Also, there are cases where educational staff provide their own technological equipment to offer digital technological means in their school units.

There are also teachers who possess the necessary digital knowledge, and by using every digital educational material and equipment at their disposal, try to transfer knowledge and expertise to their students. Properly trained educational staff are the ones who will ensure digital transformation in schools, adopt the digital and educational culture, and invest in the development of the digital skills of their students.

Teachers face obstacles and difficulties in implementing digital technology in the classroom. Encouragement from school management and support from colleagues who possess digital knowledge will significantly assist teachers in their efforts to implement digital education and introduce their students to the digital world.

In conclusion, there should be cooperation and mutual support among all those involved in the educational process for the digital transformation of education to be successful. But the teacher himself should also dedicate part of his personal time to conform with the developments imposed by modern society. The digital training of each teacher is a continuous process that aims to update his knowledge and skills. This process will be the trigger for a valuable educational experience that will provide the student population with the appropriate stimuli and the necessary skills and knowledge to meet the demands of the modern digital society.

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9. The crisis in education during the Covid-19 pandemic

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Abstract: This chapter seeks to demonstrate the crisis that education has suffered during the coronavirus pandemic. It includes research conducted in Greece and Italy. The objective of the chapter is to investigate the views of primary and secondary school teachers regarding the experiences they gained during the difficult period of the pandemic. The Covid-19 pandemic significantly affected the development of education, as educational units had to be closed and learning continued through distance education. Research showed that most teachers were not prepared for the abrupt transition to distance education. The preparedness of the relevant policy-making bodies and their support for teachers was lacking. Most teachers express a desire to be trained in new technologies to better implement distance education. Despite the difficult and adverse conditions, distance education has brought desirable results, and several educators support the future coexistence of digital and in-person education, as this blended learning model completes the educational process.

Keywords: distance education, pandemic, teachers

1. INTRODUCTION

The significant developments recorded in the 21st century at the socio-economic and political level have highlighted the role played by new technologies on the international stage. Their rapid development greatly affects society and education. New technologies, with their potential to improve services provided and to promptly and quickly complete various tasks, contribute to the optimization of educational work. Several educational organizations have recently been utilizing new technologies and adopting computer-assisted teaching methods.

The era of the Covid-19 pandemic was a brake in the rapid progress of the economy, society, and education. Humanity suffered a shock and governments worldwide, in cooperation with each other, imposed harsh measures to limit the spread of the virus, and at the same time to continue people's daily lives, as much as possible. This unexpected situation that arose brought a crisis to education and the ministries of education and the relevant policy-making bodies of several countries recommended the implementation of distance education to continue the educational process. Distance education was considered the most appropriate method at that time, so that students would not be cut off from their educational path and teachers could continue teaching. The use of technology is crucial in the implementation of distance education and during the pandemic, new technologies have greatly assisted education, as they have allowed schools and teachers to be in direct connection with students and provide them with high-quality learning.

The objective of the chapter is to investigate the views of primary and secondary school teachers regarding the experiences they gained during the period of the pandemic regarding distance education and the difficulties they faced with the implementation of distance education. Sometimes when teachers use technology, they have negative feelings (Al-Fudail & Mellar, 2008). The chapter also examines the preparedness that existed with the use of digital technology, and the cooperation that was achieved with the principal and their colleagues during the pandemic. At the same time, the in-

terest of the chapter focuses on investigating whether and to what extent educational units responded to distance education and to what extent the acquired experiences of teachers contributed to the possible implementation of distance education in the future. In general, the teachers participating in the surveys had to answer questions regarding distance education, their familiarity with this educational method, as well as the experiences they ultimately gained during the coronavirus period.

This chapter consists of an introduction, which mentions the central idea of the chapter and is the crisis in education during the covid-19 pandemic. This is followed by the impact of the covid-19 pandemic on the educational crisis, which attracts the main interest of the chapter. Then, reference is made to addressing the educational crisis and the stress of teachers during the coronavirus period. The importance and the characteristics of distance education are highlighted. The contribution of new technologies to distance education follows. The director's-leader's as well as teacher's contribution to distance education are highlighted. The objective, methodology and samples of the chapter are listed. This is followed by a presentation of the results of the chapter. Towards the end of the chapter, the conclusion and suggestions for further research in the future are presented.

2.THE IMPACT OF THE COVID-19 PANDEMIC ON THE EDUCATIONAL CRISIS, ADDRESSING THE EDUCATIONAL CRISIS

2.1 The impact of the Covid-19 pandemic on the educational crisis

It is undeniable that the emergence of the Covid-19 coronavirus has had a significant impact on the modern world, changing life worldwide. Many countries around the world, under these circumstances, have focused their attention more on health and human safety. To address the crisis created by the pandemic, new education methods were designed and implemented that were deemed necessary to address the emergency of the pandemic. Teaching was reorganized and several educational organizations implemented distance education, as it was considered the main method of education so as not to interrupt the educational process. Distance learning consists of continuing the educational process (Weeden & Cornwell, 2020), when face-to-face teaching is not possible, as it is not subject to time and place constraints. This educational method was something that the educational community became aware of for the first time. Many educators did not view the whole undertaking imposed by the circumstances with such a positive attitude. Although education was not completely ready for the rapid and abrupt technological developments, distance education worked despite the unfavorable conditions.

During the coronavirus crisis, educational institutions were forced to innovate in order to effectively deal with the unprecedented situation they found themselves in. During the coronavirus period, teachers were forced, as schools were closed, to abruptly transition from traditional face-to-face teaching to a new, for most, form of teaching, distance education. Teachers came into communication and exchanged new ideas and practices, using formal and informal communication channels. This contributed to a change in school culture, which is characterized by collectivism, co-creation, innovation, equality, and inclusiveness in education. The pandemic crisis, which contributed decisively to these characteristics, is obviously a disruption that drastically affected the educational sector and pushed educators to rethink what they should teach students and prepare them appropriately, thus rebuilding education.

The lesson of the pandemic crisis is that technology can help schools and teachers connect directly with students and provide students with access to high-quality learning. Invaluable classroom time can be productive for developing critical thinking, conducting discussion, and implementing guided

practice. Teachers can implement distance education programs to transfer content online as a complement to face-to-face learning in educational units.

2.2 Addressing the educational crisis and teachers' stress during the coronavirus

The Covid-19 pandemic, since the closure of schools, has directly affected the educational environment across the globe. The implementation of distance education was considered by education policy makers as the only way to address the educational crisis and to continue the educational process during the coronavirus pandemic.

The adverse conditions that prevailed with the emergence of Covid-19 brought concern and changed the educational routine of several teachers, who, experiencing the upcoming crisis, felt anxious and a lot of stress about how to manage the new teaching method. Also, the use of novel technology affected the well-being of teachers (Peterson et al., 2020).

The threat to the health of citizens that emerged during the pandemic, the new disease, the measures taken to combat it, and the strict isolation measures to limit the spread of the virus, had a negative effect on many people. But also, the lack of adequate information and the absence of realistic planning during the first period of the health crisis led to stressful situations for the majority of the educational community that needed appropriate remedies. Confinement at home and the removal of normality have brought psychological problems to a large part of the human population. The existence of stressful conditions for the educational staff, the presence of new educational processes, and the requirement for immediate implementation of distance education, reinforced the emergence of a psychological climate created by the events of the pandemic and contributed to creating an intense climate of insecurity and anxiety.

3. DISTANCE EDUCATION

3.1 Importance and characteristics of distance education

Distance education is education in which there is a geographical distance between the teacher and the learner. It is the educational method that is conducted remotely, supporting modern learning needs and making use of new technologies. Distance education aims to attract the learner's interest in a self-learning process through many independent exploratory steps and is not subject to limitations regarding time or space. At the same time, it enables remarkable opportunities, challenges and satisfies the need for increased flexibility in learning (Tabata et al., 2008). Distance education, as a modern challenge and a new opportunity for teaching, is gaining more ground as an alternative educational method and complementary form of learning.

Basic characteristics of distance education are its time flexibility and the fact that it is directly adapted to the needs of learners. This helps in diagnosing the specific characteristics and meeting the educational and psycho-emotional needs of learners. The main advantage of this educational method is that it promotes quality teaching design and develops multimodal educational materials. In this way, learning can respond to the capabilities, interests and abilities of students and knowledge can be transformed into a creative process.

Distance education, based on the collaborative teaching method that embraces the supportive and encouraging attitude of the teacher, contributes to the effectiveness of teaching and learning, making them more attractive for teachers and students. Also, distance education, with the help of the internet and computer networks, gives teachers and students, the opportunity to collaborate and exchange views on issues related to the educational process.

3.1 The contribution on new technologies to distance education

For some time now, there has been a gradual integration of new technologies into the educational process. In the form of communication channels, but also as a means of transferring information, new technologies contribute to the effectiveness of distance education, provided that their pedagogical characteristics are considered and they contribute to the transmission of knowledge as a creative process.

Digital learning provides high potential for the development and improvement of quality in education and contributes to the transformation of traditional teaching models. In addition to the audio-visual material of digital data, interactive videos and online platforms can be utilized. This creates a learning environment that, through brainstorming and role-playing, contributes to exploring students' psycho-emotional and social skills, acquiring cognitive and developing intellectual skills.

It is a common belief of many educators around the world that technology has a strong impact on the educational process. Knowledge, tools and methods, as well as the defining elements of technology, can contribute to the development of an educational unit (Breen et al., 2001). Several changes in schools and other educational organizations have been brought about by technology, which can activate learning and support educational work.

By utilizing modern means, such as Webex Meetings, as well as asynchronous ones, such as the e-class and the e-me platform, a method of distance education is being implemented, similar to collaborative and peer learning, which contributes to preventing knowledge from becoming a sterile process and which contributes to students having constant contact with new technologies.

Digital technologies play a dominant role in distance education, as they contribute to providing the necessary continuity and support to teachers, students and their families in ways that were unimaginable a few years ago.

The pandemic crisis created a new reality, under the light of which, the education system moved towards discovering new teaching methods that teachers and educational structures can use to further support the student population.

4. THE DIRECTOR'S - LEADER'S AND THE TEACHER'S CONTRIBUTION TO DISTANCE EDUCATION

4.1. The director's - leader's contribution to distance education

New technologies, with their rapid development and the Covid-19 crisis, have played a decisive role in the course of humanity, changing people's everyday lives. The pandemic caused the emergence of several restrictions on public life, unthinkable a few years ago (Harris, 2020) and the transformation of society into a digital one. As a result of the above, there has been a significant impact on individuals and educational structures. The pandemic greatly affected education. During the Covid-19 pandemic, learning processes changed and in-person teaching became distance learning, with the help of distance learning. At that time, the leading role of technological means contributing to the digitalization of education was also highlighted.

Leadership, and specifically networked-collaborative-distributed leadership during the pandemic, played an important role in education through digital social media (Netolicky, 2020). The use of social networking platforms and media, in the uncertain era of the pandemic, by principals, teachers and educational organizations around the world, was done to meet educational needs and complete courses and processes (Netolicky, 2020).

Educational leaders have attempted to influence others using a laptop screen, a phone, or Google Meet, IP telephony, and video conferencing. They have also practiced their leadership by implement-

ing digital platforms such as Zoom. Beyond issues related to material resources, the managers-leaders had to deal with problems related to health and, in particular, mental health. They had to resolve arising issues related to the negative psychology of the members of their educational unit, which were likely to lead to tensions, conflicts, and spontaneous outbursts of psychological discharge, bringing about a balance between technology and pedagogy (Harris, 2020).

Collaborative leaders, based on collaboration, strive to have a thorough and complete knowledge of the crisis conditions prevailing in the educational environment. Collaborative professionalism, especially collective autonomy, collective effectiveness, responsibility, initiative, shared work, shared meaning and purpose are principles that were integrated with collaboration in the era of the pandemic crisis (Netolicky, 2020).

4.1 The teacher's contribution to distance education

Two-way communication is essential in distance education, as it aims to benefit teachers and students. It provides direct instructions for sharing knowledge relevant to the learning content. New ways of assessing students must be invented by the teacher, so that their learning levels can be properly and objectively assessed.

The capacity and functionality of the new technology and the skills of the teacher relate to new ways of assessment, so that distance education can be used effectively. Also, distance education, by using new technologies, can facilitate individual and collective learning which enables a change in educators teaching methods (Peck et al., 2009).

Teachers must maximize and accelerate their actions regarding educational processes, as they are shaped by the progress of modern technology. This is because the development of new technologies gives a new dimension to education by improving teaching and learning (Wang & Wang, 2009). Hence teachers must cultivate their skills by systematic practice.

The teacher, through constant and two-way communication with the learners, assists them in achieving their learning goals and addressing difficulties that arise during the educational process. With empathy and with the help of guided teaching and direct feedback, the teacher can guide and encourage the students in the learning process. Also, he can foster students' interaction in distance learning by utilizing new technology tools, like blogs, and wikis (Beldarrain, 2006).

In distance education, the instructor organizes the material and plans the teaching, processes, and assessment. He also uses synchronous and asynchronous activities, encouraging the student's self-education. The trainer, despite the existence of an electronic educational framework, aims to inspire and guide the trainee. The teacher must maximize and accelerate his actions regarding learning processes, which are differentiated with the progress of new technologies.

Within the new educational environment, as shaped by distance education, the teacher changes, innovates, and evolves. In other words, the educational role of the teacher shifts to strengthening, counseling, and supporting students and their familiar environment, so that students can improve their psycho-emotional skills and learning abilities.

5. OBJECTIVE, METHODOLOGY AND SAMPLES OF THE CHAPTER

5.1 Objective of the chapter

The objective of the chapter is to investigate the views of primary and secondary school teachers regarding the experiences they gained during the difficult period of the pandemic.

5.2 Methodology of the chapter

To carry out the chapter a quantitative research method was conducted. Specifically, a fully structured questionnaire was used in Greece (Tsapardoni, 2023) and a semi-structured questionnaire in Italy (Doz et al., 2023). The questionnaires were also used as a means of collecting data. The questionnaires were structured online and the responses were collected. To capture the views of the samples, most of the questions in the Greek questionnaire were closed structured questions, while in the Italian questionnaire, the questions were open-ended.

5.3 Samples of the chapter

The samples of the chapter are primary school teachers in Greece and primary and secondary school teachers in Italy. No sampling method was used to select the sample. Thus, the results cannot be generalized to the wider educational community. The research samples that completed the questionnaire in full amount to 161 participants in the Greek sample (Tsapardoni, 2023) and 270 participants in the Italian sample (Doz et al., 2023).

6. RESULTS OF THE CHAPTER

In the Greek sample, of the participants in the survey regarding gender, most teachers were female (75.2%). In terms of age, the predominant age group was 41 years and older (69.5%). Regarding the employment relationship, many teachers were permanent (85.1%). Furthermore, most teachers had experience in primary education of more than 15 years (63.4%) (Tsapardoni, 2023). The Italian sample included 270 teachers, of whom 239 were women, 88.5 percent of the total sample. The mean age was 49.5 years (SD = 9.74). The teachers worked in primary (n = 135) and secondary (n = 135) schools (Doz et al., 2023).

Regarding the Italian sample most of the participants in the study reported negative emotions, such as anxiety 36.6 percent, stress 29.2 percent, helplessness 19.2 percent, confusion 18.8 percent, inadequacy 10 percent and nostalgia 6.7 percent. Furthermore, 61 percent of primary school teachers were more reluctant than 38 percent of secondary school teachers. It is also worth noting that 74 percent of older teachers were more resistant to the implementation of distance education than 26 percent of younger teachers (Doz et al., 2023).

In the table below, the terms m, SD, and SE refer to the mean, standard deviation and standard error, respectively. To calculate the Mean, Standard Deviation and Standard Error, the following correspondence was used: Not at all: 0-2, Few times: 2-4, Sometimes: 4-6, Several times: 6-8, Always: 8-10 (Tsapardoni, 2023). The results of the evaluation of the experience (Table 1) show that there were issues related to the pandemic and distance education such as health and difficulties in its implementation. Most of the Greek teachers (44.7%), who participated in the survey, responded that several times the emergence of the pandemic phenomenon and the implementation of distance education created anxiety for them. Much of the participants (29.8%) reported that sometimes the stress they experienced during the Covid-19 pandemic using distance education caused them physical fatigue and affected their work performance. A large percentage of the teachers participating in the survey (31.1%) emphasized that stress several times caused them mental fatigue and this had an impact on their work performance. On the other hand, several participants (30.4%) reported that several times during the pandemic, they felt dissatisfied (Tsapardoni, 2023).

Table 1. Health issues during the pandemic and difficulties in implementing distance education in the Greek sample.

	n(Frequency)	% (Percentage)	m (Mean)	SD (Standard Deviation)	SE (Standard Er- ror)
Did the emergence of the pandemic phenomenon and the use of distance education create anxiety for you?					
Always	32	19.9			
Several times	72	44.7	6.33 (Several times)	2.061	0.162
Sometimes	34	21.1			
Few times	17	10.6			
Not at all	6	3.7			
Did the stress you experienced during the pandemic using distance education cause your physical fatigue and affect your work performance?					
Always	10	6.2			
Several times	47	29.2			
Sometimes	48	29.8	4.87 (Sometimes)	2.303	0.181
Few times	34	21.1			
Not at all	22	13.7			
Did the stress you experienced during the pandemic using distance education cause your mental fatigue and affect your work performance?					
Always	15	9.3			
Several times	50	31.1			
Sometimes	45	28	5.13 (Sometimes)	2.354	0.185
Few times	32	19.9			
Not at all	19	11.7			
Total	161	100.0			

At the same time, in the Greek sample teachers were asked about the possible benefits they gained from implementing distance education, as well as the main difficulties they encountered, through their experience, when implementing this educational method. The teachers who participated in the survey claimed that they encountered several challenges and gained positive experiences -benefits during the implementation of distance education. The application of electronic media, their handling and gaining familiarity with them, as well as learning new teaching methods, were some of the benefits they gained. Also, preparing teachers for possible similar cases in the future, adapting to crisis situations such as the pandemic, and using alternative forms of communication in case of emergency, were other challenges and benefits they highlighted (Tsapardoni, 2023).

However, the difficulties that the teachers participating in the research had to face during the pandemic were more numerous and significantly more significant (Tsapardoni, 2023). Such were the fatigue and health problems that arose from long hours of computer use, physical problems such as back pain, eye strain, dizziness, and stress. Moreover, the management of materials, technical problems and the occurrence of poor internet connections are some other negative elements that were presented during the implementation of distance education. Other difficulties were the isolation and insecurities they felt regarding the security of their personal data, anxiety, and fear for the learning process, as most teachers were not familiar with distance education. It was found that the existence of insufficient interactions between teachers and students created difficulties on both sides (Guzzo et al., 2022).

The Greek sample examined if there existed a correlation between seniority and age of primary school teachers and health problems, either psychological or physical related to the implementation of distance education enforced by the lockdown of the Covid-19 pandemic. Using inductive statistics, the existence of correlation between the two variables was tested. For the variable of age of participating primary school teachers, no statistically significant correlation emerged in connection with body or mental health problems. For the variable of seniority however, we detected statistically important correlation at the level of $p=0.05$ or the level of $p=0.01$. The results of the evaluation of the experience (Table 2) show that there were several health problems (Tsapardoni, 2023).

Table 2. Job experience versus health problems correlation results in the Greek sample.

1st variable	2nd variable	Correlation	Pearson Coefficient	Level of statistical significance
Job experience	anxiety	positive	0.238	0.01
	Physical fatigue	positive	0.252	0.01
	Mental fatigue	positive	0.166	0.05
	Satisfaction	null		
	Transcendence of endurance limits	positive	0.179	0.05
	depression	null		
	touchiness	null		
	confusion	positive	0.232	0.01
	disillusionment	positive	0.265	0.01
	migraine	positive	0.197	0.05
	> Arterial pressure	positive	0.270	0.01
	Alcohol abuse	null		
	>smoking	null		
	Sleep disorders	positive	0.178	0.05
	unhappiness	positive	0.230	0.01
	Feel of urgency	positive	0.340	0.01
Feel of destitution	positive	0.237	0.01	

Depression, anxiety and high levels of stress have been documented by several works in China (Wang et al., 2020) and elsewhere. According to Zolotov et al. (2022), fear could be considered the most significant factor that has as a result mental health problems. They conducted a study among university students in Israel which consisted of a sample of 370 students. According to their results a weak correlation was found between fear and the age of the participating students. Also, females reported higher levels of fear than males. Lower levels of fear were reported among medical students. The correlation of fear due to Covid-19 and depression, exhaustion, loneliness, nervousness and feelings of anger was also studied. Exhaustion and loneliness are the conditions most closely connected with fear, according to the students, who took part in their study.

Nevertheless, according to Nikolopoulou and Kousloglou (2022), in their study, most teachers were able to address the difficulties encountered through mutual support, as well as cooperation and communication with colleagues (Tsapardoni, 2023).

In the Italian sample 50.4 percent of teachers pointed out difficulties related to the organization of distance education, the management of technical issues 35.9 percent, poor digital skills 14 percent, and incomplete instructions for the implementation of distance education 5.5 percent. Furthermore, 63.2 percent of primary school teachers reported having insufficient digital skills compared to 37 percent of secondary school teachers (Doz et al., 2023). Primary school teachers implemented less modern teaching methods compared to secondary school teachers. This may be due to the limited technological skills of younger students. The technical difficulties of distance education related to the lack or limited technical assistance to teachers are highlighted (Guzzo et al., 2022).

Also, in the Italian sample the main difficulty that teachers had to face when implementing distance education concerned organizational issues, such as issues of planning and implementing distance education and the lack of appropriate teaching materials. Additionally, 36 percent of teachers experienced technical difficulties, such as the lack of digital devices and inadequate equipment, as well as the lack of an internet connection. 14 percent of the sample emphasized that their digital skills were not good and this was an obstacle to the successful use of distance learning (Doz et al., 2023). Moreover, older teachers reported having significantly more technical difficulties and poorer digital skills compared to younger teachers. It is worth noting that in the Italian sample some teachers made use of only synchronous or asynchronous learning.

As far as the readiness for the implementation of distance education in the Greek sample, most participating teachers (44%) reported that they were not at all prepared to implement distance education. Most of the participants in the teacher survey (40.4%) claimed that the ministry of education's instructions on distance education helped them a little to overcome difficulties and problems that arose during its implementation. Many teachers (26.7%) responded that there was a high degree of preparedness on the part of the school administration for distance education during the period of the Covid-19 pandemic. Also, many teachers (39.1%) reported that during the pandemic and the implementation of distance learning, there was great collegiality among teachers (Tsapardoni, 2023). According to Nikolopoulou and Kousloglou (2022), their research highlights that due to the unexpected situation created by the pandemic, educational units were found unprepared for appropriate support.

According to Guzzo et al. (2022), their research points out that in Italy teachers were found to be quite unprepared regarding the management of distance education during the pandemic. Many teachers in this survey reported that they did not receive adequate training regarding the methodology and implementation of distance education before the pandemic.

Finally, in the Greek sample, teachers were asked about the experiences they gained during the implementation of distance education and the possibility of its future use. Many teachers (48.4%)

claimed that during the pandemic their daily life and their way of working was affected for the worse. Most teachers (44.8%) responded that they are not at all likely to use distance education after the end of the Covid-19 pandemic. A majority of teachers (47.8%) reported that they believe that school units will return to their previous normal operation. However, there were also several teachers (39.8%) who expressed their belief in the future existence of a mixed distance and face-to-face education system (Tsapardoni, 2023). The view is reinforced that blended learning is the best approach to continue the use of digital tools within the context of an integrated educational process and thus paves the way for future implementation of alternative methodologies (Guzzo et al., 2022).

7. CONCLUSION

In conclusion, it can be said that during the coronavirus pandemic, as a result of the abrupt transition from in-person learning to distance learning, many educators and students were greatly affected. The results of the surveys showed that most teachers were not prepared for the abrupt transition to distance education. They faced several challenges, both technological and pedagogical, when implementing digital teaching. The first are related to the lack of necessary technological equipment and the fact that internet connections were insufficient and constantly interrupted. The second are related to the insufficient digital skills of teachers, as there was a lack of adequate training. The preparedness of the central administration of the ministry and the competent bodies was not the best possible, as their support for the teaching staff was lacking. On the contrary, there was cooperation and solidarity with fellow teachers to deal with problematic situations that arose.

This type of remote teaching made it difficult for both teachers and students, who experienced negative emotions during its implementation. The immediate and abrupt transition from in-person to distance education, the lack of familiarity with the new teaching method and the uncertainty about the overall course of the situation, caused negative feelings among teachers during the coronavirus period when educational units were closed.

Observing the results of the chapter, with reference to the Greek research it is illustrated that a correlation between the variables of seniority of teachers for health problems and long-distance education exists (Tsapardoni, 2023). According to Kartsoni and Patelarou (2021), the social distancing and the lockdown measures imposed have adversely affected the mental health of teachers wherever they have been imposed. Also, according to Husky et al. (2020), levels of anxiety and stress moderate to severe were experienced by university students as a result of forced confinement during the Covid-19 pandemic. Those findings have shown a correlation between the lockdown measures implemented during the Covid-19 pandemic and several mental health problems among members of the educational community such as anxiety and stress.

According to Rapante et al. (2020), who have examined the lessons of long-distance education during the Covid-19 pandemic, it is useful to design learning activities with a combination of the following characteristics: cognitive, facilitatory and social, and to adapt to the new educational requirements.

Furthermore, the Greek study highlights the need for the ministry to improve the equipment of the educational units participating in the educational process, to upgrade technological infrastructure and internet connectivity and to investigate educational and student needs regarding appropriate equipment, in order to ensure equality and quality in access and to prevent student exclusion (Tsapardoni, 2023).

In order to have digital readiness in the educational space, it is necessary to have competent leadership, which can predict and analyze data, introduce innovations such as artificial intelligence, ro-

botics, etc. Such leadership will be able to provide educational materials, adopt new curricula, and appropriate teaching models.

Most teachers express a desire to be trained in new technologies and digital tools to make online teaching easier. By integrating new technologies into the educational process, the teacher is transformed. Within the new educational environment, the role of the teacher is redefined and changes follow that contribute to the creation of self-regulated learning, which motivates students and encourages discussion and communication.

Despite the difficult and adverse conditions, distance education brought the desired results, the teaching staff largely adapted and by using new technologies, as well as the adoption of modern and asynchronous methods, was able to help students, providing them with a wealth of knowledge. Many educators support the coexistence of digital and in-person education in the future, as this blended learning model completes the educational process. Distance education should continue in the future with a fully digital educational approach (Guzzo et al., 2022), as a form of teaching that is constantly improved across the entire spectrum of school activities and is not only required in cases of an emergency.

Finally, it can be said that the Covid-19 pandemic was a disruption that activated the educational space and caused educators to revise their views on teaching and preparing students. It is therefore time to critically reflect on how this disruptive pandemic crisis can provide the impetus for the reconstruction of education.

Regarding the future, it is proposed to create networks between teachers, schools, and institutions from different parts of the world, so that the educational population can collaborate, exchange opinions, information, knowledge, experiences, and new ways of acting. In this way, education will evolve and science will progress.

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Part II
Health, Ethics and Human Development

10. Mediterranean Diet and Microbiota Gut

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Abstract: The Mediterranean Diet (MD or Med Diet), initially conceptualized by Ancel Keys, is a sustainable lifestyle giving emphasis to fresh plant foods, extra virgin olive oil and whole grains, while limiting red meat, dairy products and processed foods. In 2026, scientific focus has intensified on how this dietary pattern modulates the gut microbiota — a complex ecosystem of trillions of microbes essential for immunity, metabolism and mental health. By providing high levels of fiber, antioxidants and healthy fats, the MD offers an “eubiotic” state characterized by high microbial diversity and the production of beneficial metabolites like short-chain fatty acids. While genetics influence microbial composition, exogenous factors like diet and lifestyle are the dominant architects of the gut blueprint. Ultimately, consistent adherence to Mediterranean patterns serves as a powerful therapeutic intervention, harnessing the synergy between nutrition and the microbiome to prevent chronic disease and promote longevity. The importance of the MD and its beneficial impact to the microbiota gut and by extension to overall health, will be analyzed through this work. This analysis further explores the synergy between dietary adherence and the maintenance of systemic homeostasis via the gut-organ axes. Ultimately, the work underscores the Mediterranean Diet as a vital tool for public health, advocating for its integration into global strategies to combat the modern epidemic of non-communicable diseases.

Keywords: Mediterranean diet, gut microbiota, microbial diversity, dietary fibers, short chain fatty acids, polyphenols, eubiosis, dysbiosis, public health.

1. INTRODUCTION OF GUT MICROBIOTA

According to LeBlanc and colleagues (2013), “*A convenient ecological framework in which to examine biocontrol systems is that of the microbiome. This may be defined as a characteristic microbial community, occupying a reasonably well-defined habitat which has distinct physio-chemical properties. The term not only refers to the microorganisms involved but also encompasses their theatre of activity.*”

The human gut microbiota comprises trillions of microorganisms that significantly outnumber human cells and are essential for immunity, digestion and mental well-being. This complex ecosystem, including species like *Firmicutes* and *Bacteroidetes*, protects the host by synthesizing vitamins, enzymes, and neurotransmitters such as serotonin (Arumugam *et al.*, 2011). It also produces short-chain fatty acids (SCFAs) like butyrate, which are crucial for maintaining gastrointestinal integrity and regulating the immune system. Research highlights that dietary habits and lifestyle choices—including exercise, smoking and pollutant exposure—influence gut health more than genetic inheritance (Bhatt *et al.*, 2024, pp. 23-35). Conversely, an imbalance in this flora, known as dysbiosis, is a key contributing factor to chronic conditions like obesity and inflammatory bowel disease. Ultimately, the liver and gastrointestinal system work together as a critical defense against environmental toxins and modern dietary impacts (Valdes *et al.*, 2018).

A healthy gut is often defined by the absence of clinical conditions like Inflammatory Bowel Disease (IBD), irritable bowel syndrome (IBS), or Gastroesophageal Reflux Disease (GERD), but can

also be characterized by a lack of digestive symptoms such as bloating and irregular bowel movements. Beyond just the absence of disease, this definition emphasizes a diverse and balanced microbial structure that supports essential physiological processes. Even without a formal diagnosis, lifestyle factors like stress and poor nutrition can cause microbial imbalances that compromise overall well-being. Modern perspectives therefore view gut health as a dynamic state of microbial variety and optimal functional integrity (Van Hul *et al.*, 2024).

Increased bacteria diversity, defined by a wide number of distinct species usually indicates good gut health. High microbial diversity, subscribes to strong digestion, metabolite generation, immune system control and better nutrition absorption. As a result, quicker recovery is promoted and resistance against antibiotic use and infections is increased. Respectively, reduced variety could be connected to numerous illnesses, like type II diabetes (T2D), obesity, IBD and Cardio Vascular Disease (CVD). Athletes in general show high levels of microbial diversity, as the healthy diet in combination to the exercise provide its raise (Mohr *et al.*, 2020).

The *Firmicutes/Bacteroidetes* (F/B) ratio is often used as a metabolic health indicator, as a higher proportion of Firmicutes is associated with increased energy extraction and weight gain. The complexity of the microbiome means these ratios are not absolute measures of health (Li *et al.*, 2023). Beneficial bacteria like *Bifidobacterium* and *Lactobacillus* generally support digestion and immunity, but an overgrowth of even «good» bacteria can lead to conditions like Small Intestine Bacterial Overgrowth (SIBO). Ultimately, the presence of potentially harmful pathogens does not always result in illness, as gut health is a dynamic balance influenced by genetics, environment and lifestyle (de Vos *et al.*, 2022).

Gut health is significantly influenced by microbial metabolites like SCFAs, which provide energy to colonic cells and maintain gut barrier integrity. Additionally, bile acids and tryptophan metabolites—such as indole and kynurenine—serve as vital markers of the symbiotic relationship between host metabolism and microbial activity. Because bacterial impact is highly strain-specific, functional diversity determines whether a microbe is beneficial, neutral, or pathogenic, as seen in the contrast between benign and disease-causing *Escherichia coli* (de Vos *et al.*, 2022).

Another significant factor, which acts like a health indicator is the generation of several gases, including hydrogen, methane and hydrogen sulfide, which are by-products of microbial fermentation. Constipation-predominant IBS (IBS-C), elevated methane levels and methane-producing organisms have been linked, whereas diarrhea-predominant IBS (IBS-D) patients have been found with increased breath levels of hydrogen, hydrogen sulfide and a higher relative abundance of hydrogen sulfide-producing bacteria. A pH of 5.5 to 7 in the colon is often connected to a robust microbiota. An ideal pH environment helps the development of good bacteria, inhibits harmful organisms, maintains enzyme activity and is beneficial for nutritional absorption and digestive capability. However, pH is a changeable marker because it can change depending on a person's nutrition, health and other circumstances (Van Hul *et al.*, 2024).

Decreased levels of inflammatory markers, like calprotectin and lactoferrin, are connected to health in the gut. Inflammation detectors are affected by a variety of consideration, such as infections, illnesses and dietary habits and this could result false positives. These markers should be evaluated for both clinical and microbial data, in order to have an accurate estimation. Regarding the definition of gut microbiotas' health, there is a considerable disagreement, even several health indicators exist. Each one has its pros and cons and different variables are linked to it. Therefore, further investigations and researches are required, in order to specify the definition of gut microbiotas' health.

2. GUT MICROBIOTA AND MEDITERRANEAN DIET

Physiologist Ancel Keys was the first to establish and characterize the “concept” of the Mediterranean diet (Dinu *et al.*, 2017). Keys investigated how eating habits could possibly affect the prevalence of cardiovascular (CV) disorders. The Seven Countries Study is a well-known product of Keys’ work. The US, Finland, the Netherlands, Italy, Yugoslavia, Japan and Greece (Crete) were the seven countries that took part in the epidemiological study called the Seven County Study, which examined the relation between human health and diet (Keys, 1980, as cited in Merra *et al.*, 2020).

Countries of the Mediterranean region, where sun and temperate climate exist, are the origin of the traditional MD, which contains a lot of fruit and vegetables, using extra virgin olive oil (EVOO) as the primary fat source and consuming whole grains, legumes, nuts, seeds and herbs. It is additionally characterized by a moderate intake of fish and dairy products, a low intake of red meat and its products and low to moderate alcohol consumption, mainly in the form of wine at mealtime (Dinu *et al.*, 2017).

Food flavorings and chemical substances, are added into foods in order not only to provide a better taste, or to improve their properties, but also because they can have health benefits. The majority of the mediterranean dishes, contain prebiotic-rich foods such as garlic and onions and many of the numerous aromatic herbs, like oregano, thyme, cloves, mint, basil, pepper etc., as they have anti-inflammatory and antioxidant action (Chen *et al.*, 2022).

In 2021, scientists examined the effects of “Western”, “plant-based”, “high-fat”, “medical ketogenic” and “Mediterranean” diets on gut microbiota’s synthesis in both mice and human beings. Common dietary ingredients were found in “plant-based” and “Mediterranean” diets, by increasing the healthy microbiome composition. Consuming dietary fiber may increase specific microbial communities, such as *Bacteroides* and *Alloprevotella* and decrease other like *Porphyromonadaceae* and *Erysipelotrichaceae*. A diet with high consumption in animal protein raises *Bacteroides spp.*, *Alistipes spp.* and *Bilophila spp.*, while reduces the beneficial bacteria *Lactobacillus spp.*, *Roseburia spp.* and *E. rectale* and as a result the microbiota guts’ synthesis change (Barber *et al.*, 2023). According to this review, a traditional “Western diet” that consists of high consumption in fats, processed sugar and small consumption in fiber conducts an augmentation in *Firmicutes*, *Proteobacteria*, *Mollicutes*, *Bacteroides spp.*, *Alistipes spp.*, *Bilophila spp.*, *Enterobacteriaceae*, *Escherichia*, *Klebsiella* and *Shigella*, while decreasing the beneficial bacteria *Bacteroidetes*, *Prevotella*, *Lactobacillus spp.*, *Roseburia spp.*, *E. Rectale*, *Bacillus bifidus* and *Enterococcus*. The production of SCFAs is limited, because lipopolysaccharides (LPS), trimethylamine-N-oxide (TMAO) become more and inflammatory cytokines raise the risk for nutrition-related chronic diseases, obesity and type II diabetes. Adhesion to a plant-based diet rich in whole grains, fruits and vegetables, like the Mediterranean diet, changes the bacterial synthesis, by reducing the bacteria, LPS, TMAO and inflammatory cytokines. It finally makes the production of SCFAs even higher and the consequence is that inflammation and risk for obesity and type II diabetes are lower.

Dietary factors have been long known to affect the gut microbiota. A Mediterranean-style diet has shown to have a positive effect on the composition of the gut microbiota. Additionally, people who consume more plant-based meals have larger levels of fiber-degrading bacteria and SCFAs. Conversely, consumers who do not follow the MD, have got increased levels of TMAO, which could be associated with T2D, atherosclerosis and CVD (Wu *et al.*, 2016).

There is mutual relation between gut microbiota and nutrition. Even if the microbiota influences nutrients that have been eaten, the composition of the gut microbiota is significantly affected by food. Metabolic processes are primarily influenced by the quantity of proteins and carbs that enter the colon and are difficult to digest. Researches on the gut microbiota in fecal samples from humans and

animals showed, that any dietary differentiation could change the synthesis of the microbial flora. A well-balanced diet guarantees the development of a healthy microbiome in healthy humans, where all bacterial species coexist in a reciprocally balanced and controlled system (Valdes *et al.*, 2018).

Human gut flora imbalance may be caused by different factors, including diseases, stress and most importantly, poor dietary habits. Therefore, the type, the quality and the structure of the gut microbiota could alter if the equilibrium is upset (He, & Shi, 2017).

Many scientific studies have reported, that adopting the Mediterranean style eating pattern is linked to a specific microbiota in contrast to the Western-type dietary pattern. The microbiota that could restore the balance, should initially be with high biodiversity, which is beneficial for humans' health. This characteristic of gut microbiota has got the definition "α - diversity" and expresses the present number of species in the microbiota (Mohr *et al.*, 2020). The Western-type diet has been linked to high levels of Bacteroides and the MD pattern represents the genus *Prevotella* quite often. Increased quantities of Clostridium of cluster were found in humans who adopted the MD. Also, according to reports there was found a lower Firmicutes-Bacteroidetes analogy connected to a high adherence to the MD. Mediterranean Diet is an eating pattern rich in specific food components, like cereals, olive oil and red wine, vegetables and legumes, which each one is associated with specific microbial trains, like *Bifidobacterium*, *Faecalibacterium*, *Tenericutes* and *Dorea* in cereals, *Faecalibacterium* in olive oil and red wine, *Rikenellaceae*, *Dorea*, *Alistipes* and *Ruminococcus* in vegetables and *Coprococcus* species in legumes (Jin *et al.*, 2019).

The Mediterranean diet boosts longevity and quality of life. It may increase life expectancy and enhance general health and well-being. There is also evidence, that MD supports gut health by promoting a balanced microbiota, reducing harmful inflammation and fostering the growth of beneficial microorganisms. Specific food groups named below, analyze their effectiveness to healthy microbiota gut (Knoops *et al.*, 2004).

2.1 High Fiber Content

Fiber functions as a prebiotic and can be found in foods like whole grains (such as oats, barley and brown rice), legumes (such as beans, lentils and chickpeas), fruits and vegetables (particularly artichokes, asparagus and garlic). Prebiotics, primarily lactobacilli and bifidobacteria, support the activity and the high levels of good gut bacteria. This can contend the preservation of a balanced and varied microbiota, which is essential for gut health in general. Non-digestible fibers, which are abundant in certain diets, pass through the colon undigested. Gut bacteria ferment them there, promoting the growth of advantageous species like *Lactobacillus* and *Bifidobacteria*. SCFAs, such as butyrate, which promote gut integrity, lower inflammation and feed colon cells, are produced when these bacteria break down fiber (He, & Shi, 2017).

2.2 Healthy Fats (monounsaturated fatty acids - MUFAs)

Monounsaturated fats and polyphenols found in olive oil, a main product of the Mediterranean diet, have been demonstrated to have anti-inflammatory effects and may help keep good bacteria like Bifidobacteria. Nuts, seeds and fatty fish (salmon, mackerel and sardines) are other good sources of healthy fats. Maintaining the integrity of intestinal cell membranes and controlling the inflammatory response healthy lipids are demanded, specifically monounsaturated fats. Additionally, omega-3 fatty acids from fatty fish can help control the composition of microorganisms and reduce inflammation in the stomach. Omega-3 fatty acids may also promote the growth of good bacteria while suppressing bad ones (Li *et al.*, 2023).

2.3 Polyphenols (anti-oxidant rich foods)

Polyphenols from berries, olive oil, and nuts act as prebiotics that enhance microbial diversity and promote the growth of beneficial bacteria like *Bifidobacterium* (Li *et al.*, 2023). Their anti-inflammatory properties, particularly oleocanthal in olive oil, help reduce gut permeability and inflammation, aiding in the management of conditions such as Crohn's disease and ulcerative colitis. By lowering "leaky gut" risks and preventing flare-ups, these compounds are essential for maintaining a resilient and balanced gut microbiome (Aleman *et al.*, 2023).

2.4 Vitamins

Vitamins are important for preserving a wholesome gut environment, fostering the development of beneficial bacteria and reducing the process of inflammation. The basis for a healthy and balanced gut microbiome is a Mediterranean diet rich in these vitamins. When taken in big quantities or administered to the large intestine, certain vitamins may have a positive impact on the gut microbiota because they increase the abundance of complementary vitamins (A, B2, D, E and beta-carotene), as well as the diversity and richness of microorganisms (A, B2, B3, C, K), by producing SCFAs (C) or by increasing their abundance (B2, E). Vitamins A and D, act as regulators of the gut immune response or barrier function and this could lead to affection of the gastrointestinal (GI) health or the microbiome (Calder *et al.*, 2022).

2.4.1 Vitamin A (Beta-Carotene and Retinoids)

Vitamin A, found in carrots, sweet potatoes and leafy greens, is crucial for immune system regulation and maintaining the protective gut lining by aiding the synthesis of mucin proteins (LeBlanc *et al.*, 2013). Adequate intake promotes a balanced microbial equilibrium, encouraging beneficial bacteria like *Lactobacillus* while hindering pathogens. A deficiency can lead to dysbiosis, reduced microbial diversity, and impaired tissue repair, exacerbating inflammatory gut conditions (Pham *et al.*, 2021).

2.4.2 Vitamin D (Calciferol)

Vitamin D, sourced from fatty fish, egg yolks and sunlight, is critical for maintaining the gut barrier and regulating immune responses against inflammation and infection. It promotes microbial diversity by encouraging the growth of beneficial bacteria like *Lactobacilli* and *Bifidobacteria* while inhibiting the spread of harmful pathogens. Conversely, a deficiency in Vitamin D is a known risk factor for gastrointestinal diseases, including IBD and colon cancer, due to reduced microbial diversity and compromised gut lining integrity (Bellerba *et al.*, 2021).

2.4.3 Vitamin C (Ascorbic acid)

Vitamin C, abundant in citrus fruits, bell peppers, and strawberries, is a potent antioxidant that protects the gut lining from oxidative stress and inflammation. It encourages the growth of beneficial gut bacteria while restricting harmful ones, thereby helping to maintain microbial balance and immune function. Inadequate intake of vitamin C can hinder gut motility, impair the repair of gut cells and collagen, and increase the risk of infections (Calder *et al.*, 2022).

2.4.4 Vitamin B Complex (B1, B2, B3, B5, B6, B7, B9, B12)

B vitamins, sourced from whole grains, legumes and fish, are essential for energy metabolism, immune function, and maintaining gut motility. They serve as vital nutrients for both the host and the microbiota, supporting beneficial bacterial survival while suppressing pathogens to prevent dysbiosis and inflammatory conditions like colitis. B-vitamins include B1 (thiamin), B2 (riboflavin), B3 (nic-

otic acid/niacinamide), B5 (pantothenic acid), B6 (pyridoxine), B7 (biotin), B9 (folate) and B12 (cobalamin) and are grouped together due to their water solubility, despite their various differential functions (Ken *et al.*, 2019).

Thiamin (B1), sourced from meat, grains, and legumes, is an essential cofactor for enzymes and gut bacterial health. Riboflavin (B2), found in leafy greens and liver, promotes beneficial bacteria like *Bifidobacterium* to boost butyrate production, while Niacin (B3) from animal and plant sources supports vital metabolic, nervous and digestive functions. Pantothenic acid (B5), found in liver and whole grains, is essential for energy metabolism, and its deficiency is linked to fatigue and insomnia (Yoshii *et al.*, 2019). Vitamin B6 supports immune regulation and the gut-brain axis by promoting beneficial bacteria like *Bacteroides*, while Biotin (B7) is a key metabolic cofactor found in nuts and seeds, though its absorption can be inhibited by raw egg whites. Folate (B9), found in leafy greens and legumes, is essential for DNA synthesis and maintaining the gut barrier, while its deficiency reduces key beneficial bacteria like *Firmicutes*. Cobalamin (B12), sourced from animal products and fortified yeast, supports microbial diversity and nerve function; low levels can lead to gut atrophy and increased susceptibility to infections (Uebanso *et al.*, 2023).

2.4.5 Vitamin E (Alpha-Tocopherol)

Alpha-tocopherol (vitamin E), found in nuts and olive oil, protects the gut lining from oxidative damage and supports a diverse, anti-inflammatory microbial environment. A deficiency can weaken the gut barrier and reduce SCFA production, potentially leading to increased permeability, harmful bacterial overgrowth, and inflammatory conditions like IBD (Pham *et al.*, 2021).

2.4.6 Vitamin K (phylloquinone)

Vitamin K-rich foods like leafy greens and fermented vegetables support gut health by maintaining epithelial cell function and promoting the production of Short-Chain Fatty Acids (SCFAs), which reduce inflammation and strengthen the gut barrier (Arumugam *et al.*, 2011). Because vitamin K is also synthesized by beneficial microbes, a deficiency can signal microbial imbalances, leading to impaired gut permeability and increased risk of inflammatory conditions (Pham *et al.*, 2021).

2.5 Omega-3 Fatty Acids (ω 3)

Omega-3 fatty acids from fish, seeds, and nuts promote a healthy gut environment by reducing inflammation and balancing immune responses. Research by Stull and Weir, (2023) indicates that edible insects are also a significant source of omega-3s and fiber, offering a nutrient-dense option to positively modulate the gut microbiota.

2.6 Gut-Boosting Proteins

Fish, seafood, legumes and nuts provide high-quality proteins and bioactive compounds that support gut health through antioxidant, anti-inflammatory and prebiotic effects. Specifically, fish proteins like immunoglobulins defend against infections, while the high fiber content in legumes promotes a healthy microbiota composition (Chen *et al.*, 2022).

2.7 Fermented Foods

Fermented foods such as yogurt, kefir, and traditional Mediterranean pickles enhance the bioactivity of nutrients through lactic acid bacteria, which transform food components to improve nutritional value and shelf life (Naureen *et al.*, 2022). Regular consumption of these probiotic-rich items supports gut

health by balancing the microbiota and reducing inflammation, especially within the context of the Mediterranean diet's emphasis on natural, low-sugar dairy and vegetable products (Şanlier *et al.*, 2019).

2.8 Reduced Red Meat and Processed Foods

The Mediterranean diet limits red and processed meats, which are linked to reduced gut diversity and higher risks of diseases like colorectal cancer due to their saturated fats and preservatives. Conversely, the modern diet's reliance on food additives—such as emulsifiers and sweeteners—has been increasingly shown to damage the gut microbiome and trigger inflammatory conditions like IBD and IBS (Whelan *et al.*, 2024).

3. A SYMBIOTIC RELATIONSHIP

A healthy gut microbiome is crucial for nutrient metabolism, pathogen inhibition and immune regulation and diet can highly affect it (Stull, & Weir, 2023). The gut microbiota refers to the diverse community of microorganisms (bacteria, viruses, fungi, protozoa and other microbes) that live in the gastrointestinal tract. These microbes play an essential role in digestion, metabolism, immune function and even influence mental health and disease susceptibility.

The Mediterranean diet and gut microbiota share a mutually beneficial relationship in a variety of fields, like, dietary fiber, polyphenols and antioxidants, healthy fats and microbial diversity and fermented foods. The raised consumption in dietary fibers, as many foods in the Mediterranean diet are rich in dietary fiber, acts as a prebiotic. Prebiotics are non-digestible compounds that feed the beneficial bacteria in the gut. For instance, fiber-rich foods like fruits, vegetables and legumes help advance the growth of beneficial bacteria like *Bifidobacteria* and *Lactobacilli*. These bacteria, in turn, support digestion and the generation of SCFAs, which are important for gut health and inflammation regulation. Regarding the antioxidant activity, foods like fruits, vegetables and olive oil are rich in polyphenols, which have antioxidant and anti-inflammatory properties. Polyphenols are also metabolized by the gut microbiota, and the interaction between polyphenols and specific microbial species can enrich their beneficial effects on health. For example, polyphenol consumption can increase the abundance of *Prevotella* and *Roseburia*, bacteria associated with improved gut health. Olive oil, a staple of the Mediterranean diet, is rich in monounsaturated fats, which not only provides anti-inflammatory benefits but also contributes to a more varied gut microbiota. Studies report that, olive oil can positively influence microbial diversity, as it can create a more balanced and beneficial gut environment. The Mediterranean diet includes fermented foods like yogurt and cheese, which are rich in probiotics. These live microorganisms can directly import beneficial bacteria into the gut, helping to keep a healthy microbiota balance.

The symbiotic relationship between the Mediterranean diet and gut microbiota supports general health in various ways. The diet affects the balance of gut bacteria, improving overall health. A study in *Nutrients* found that the Mediterranean diet boosts beneficial gut bacteria (Wu *et al.*, 2016). This relationship is complex, with the diet influencing the gut microbiota and *vice versa*. Adhering to the Mediterranean diet promotes a diverse and healthy gut microbiota, which is essential for efficient digestion and a robust immune response. This dietary pattern, rich in fiber, healthy fats, and polyphenols, effectively combats dysbiosis—an imbalance in gut bacteria linked to obesity and metabolic diseases—by restoring microbial equilibrium. Furthermore, the diet's anti-inflammatory properties help lower systemic inflammation, reducing the risk of chronic conditions like heart disease and diabetes. It also influences the gut-brain axis, with evidence suggesting that a balanced microbiota can lead to improved mood and better mental health outcomes.

4. CONCLUSIONS

The Mediterranean Diet, regarding the last researchers' evidence, has proved its relation to the health of the microbiota gut. Across a huge variety of diets, the Mediterranean Diet is the most widely studied, by improving health, mentality, wellbeing and longevity and last but not least it is common knowledge that adopting the Med Diet it benefits the health of gut microbiota.

Dietary fibers, originated in plant foods like fruits, vegetables and cereals, polyphenols, which exist in virgin olive oil and olives, ω -3 fatty acids, which are contained in oily fish, seafoods and nuts, almost all the types of Vitamins, A, the complex of vitamin B, C, D, E and K, a wide range of elements which are included in fresh fruits and vegetables and fermented foods, like olives, pickles and fermented meat or vegetables, are the basis of the Mediterranean Diet and consist the healthiest way of eating, according to the scientists.

Even if the MD benefits are plenty, it is a diet that not many countries follow and more often because of the region they belong to. For the Mediterranean countries, it is actually a diet easy to adopt, because there is an abundance of olive oil, fresh fruit and vegetables for most of the year, opposing to other countries. Different cultures and eating habits, or even lifestyle are factors which lead to avoiding the MD adoption.

Future researches should concentrate on identifying the mechanisms by which the MD affects the human health and the improvement of gut microbiotas' health. Also, the exploration of the mechanisms that MD uses to regulate brain signaling (microbiota – gut – brain axis), comprising appetite and metabolism control, would constitute further future findings.

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Part III
Historical, Philosophical and
Interdisciplinary Perspectives

11. De *summetria* a *simetría*: El tránsito de la conmensurabilidad antigua y la proporción medieval al paradigma invariante moderno

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Abstract: This study examines the evolution of the concept of symmetry, from its absence as an explicit term in ancient Greece to its consolidation as a principle in the medieval era and as an invariant in modern physics. It classifies the concept according to three frameworks: a) J. Roche's principle-argument scheme; b) R. Carnap's figurative-normative distinction; c) K. Brading and E. Castellani's implicit-explicit distinction. The article is structured in three parts. The first section analyzes the term beginning with the studies of the Presocratics. In this period, symmetry appears implicitly, associated with notions of harmony, order, beauty, balance, and indifference. Since no specific term existed to define its meaning, symmetry is classified here as qualitative and aesthetic. The second section addresses the medieval and modern periods. The notion becomes linked to proportionality (*summetria*) and divine perfection, manifested in architecture, art, and natural philosophy during the medieval era. In modernity, symmetry is transformed into a normative principle. In each historical stage, the evolution of the term is distinguished by classifying it as: (a) symmetry as argument (indifference, Greece) versus principle (theoretical norm, modernity); (b) implicit symmetry (qualitative, aesthetic) versus explicit symmetry (transformational invariance). Finally, the reflections and conclusions focus on warning against anachronism and advocating for careful conceptual reconstructions.

Keywords: symmetry, harmony, invariance, explicit, argument, principle

1. INTRODUCCIÓN

En el *Diccionario etimológico de términos geométricos* de Fernando Lafarga (s/f) se recoge que el término *simetría* proviene del griego *συμμετρικ*, que viene formado por el prefijo *συμ* (*sym*=con, en conjunto), la raíz *μετρον* (*metrón*= medida) y el sufijo *ια* (*ia*=cualidad), y es entendido como: (a) la medición en conjunto de cualidades; (b) reducción a una medida común; y (c) justa proporción o medir por comparación. Ahora bien, aunque el origen etimológico de la palabra es griego, ellos – griegos – en realidad no tenían un término como *simetría*, y, consecuentemente, mucho menos una definición explícita. Más bien, los griegos asociaban un conjunto de nociones, tales como: *proporción, equilibrio, permanencia, indiferencia, armonía, orden y belleza* a la significación de lo que, posteriormente, adquiere la nominación de *simetría* (Azcarate, 1873, p.354). La ausencia del término *simetría* en el mundo antiguo, lleva a los griegos a mostrarla de una forma *implícita* relacionándola con el conjunto de nociones antes citadas. Bajo esta perspectiva, tomamos como punto de partida la asociación que hacían los griegos por *simetría* (*proporción, equilibrio, belleza, armonía, orden y equivalencia*) para dar un paso hacia adelante y clasificar la noción de *simetría* bajo tres esquemas: a) dentro del esquema de Branding y Castellani como *simetría implícita*; b) bajo el esquema carnapiano como *concepto clasificador*; y c) como *argumento y principio* bajo el esquema de Branding-Castellani y Roche. El distinguir la noción de *simetría* bajo estos tres esquemas permite dar cuenta de la evolución y transformación del concepto en la ciencia y su aplicación bajo la reconstrucción histórica y reflexión filosófica de la física.

2. LA ILUSIÓN DE LA SIMETRÍA EN EL MUNDO GRIEGO: ENTRE LA ANALOGÍA Y LA CONMENSURABILIDAD

Ángel Ruiz en su obra *Filosofía, historia y filosofía de las matemáticas* (2003) sostiene que la ciencia y la filosofía se iniciaron con los estudios acerca de la naturaleza de los denominados presocráticos griegos. Particularmente Ruíz resalta la figura de Thales quien funda su escuela en la ciudad de Mileto. Para la escuela de Thales de Mileto, el factor constante presente en la naturaleza es la descripción de un mundo ordenado y armonioso; un mundo bello en función de su orden y armonía. El mundo guarda un orden o equilibrio relacionado con la belleza gracias a disposiciones de los dioses (Ruíz, 2003, pp. 33-31).

Reafirmando lo anterior, Castillo y Álvarez en su artículo “Principio, orden, belleza y simetría en la investigación griega acerca de la naturaleza o *physis*” (2024) sostienen que los presocráticos (Thales, Anaximandro, Anaxímenes, Pitágoras, Heráclito, Parménides) tenían como objetivo común encontrar el principio natural que subyace en lo terrenal. Para ellos, este principio esta subyugado a las disposiciones divinas que le otorgan la regla de orden o de equilibrio a la naturaleza (Castillo y Álvarez, 2024, p.175).

En referencia a los presocráticos, Simplicio en su *Física* expone: “Anaximandro dice que el principio básico no es ni agua ni ningún otro de los llamados elementos, sino otra naturaleza infinita de la que todos los cielos proceden, y los infinitos cosmos que hay en ellos” (DK12 A9). El principio básico que refiere Anaximandro, y que recoge Simplicio, es *ápeiron* y es entendido como el principio divino, principio de todas las cosas en tanto que sustancia universal. Al mismo tiempo, del *ápeiron* se engendran todas las cosas, permaneciendo en las variaciones y unificando la multiplicidad (Castillo y Álvarez, 2024, p. 177).

Cada uno de los presocráticos (Thales, Anaximandro, Heráclito, etc.) pasa a establecer y a defender su propia hipótesis acerca del principio fundamental de la naturaleza o *arché*. Para Anaximandro es *ápeiron*; Thales propone el agua; Anaxímenes defiende el aire. Lo cierto es que, independientemente del elemento al que refieran, todos los presocráticos están de acuerdo en que *arché* es un principio que mantiene el equilibrio de las cosas, del mundo y del cosmos ya que es aquello que permanece en las variaciones del mundo.

Con relación al carácter estable y permanente frente a las variaciones o cambios del *arché*, en “A critical study of symmetry in physics from Galileo to Newton” (1987) John Roche afirma que “según Aristóteles, Anaximandro sostenía que la tierra mantiene su lugar debido a su indiferencia. Movimiento hacia arriba y hacia abajo y hacia los lados, son todos iguales a lo que se establece en el centro y con indiferencia relacionada con cada punto extremo” (1987, p.6). Entonces, según Roche, la *indiferencia* es vista por los antiguos como *equilibrio* en el sentido de que aquello que está en equilibrio es indiferente frente algún cambio. En este sentido, sentencia Roche (con relación a la *arché* y a la indiferencia) que “[...]un concepto o definición de simetría exacto no existe en la antigüedad, lo que más se asemeja es la indiferencia” (1987, p.6).

Entonces, y siguiendo lo anterior, la Tierra es *simétrica* porque está en *equilibrio* gracias a la *indiferencia* que presenta su forma geométrica (Roche, p.6) entendiendo la indiferencia como la *equidistancia* que existe entre todos los puntos. Podemos considerar esto como la primera noción de simetría ya que, y siguiendo a Anaximandro y las reflexiones de Roche, aquello que es simétrico está en equilibrio y es *indiferente*. Expone Roche:

En Anaximandro tenemos al parecer el primer argumento de la simetría en la física. La Tierra está en equilibrio debido a su perfecta simetría o la indiferencia con respecto a todas las direccio-

nes en el espacio [...] Estas ideas representan un principio de simetría, por tanto, Anaximandro bien puede haber sido responsable del posterior compromiso de los astrónomos griegos con un cosmos esférico. Las cosmologías babilónicas, egipcios y griegos anteriores a las ideas de Anaximandro no concibieron el universo como una esfera. (Roche, 1987, p.6)

Roche considera la *indiferencia* como *argumento* de simetría, en tanto atributo de la cosa, y que es Anaximandro quien coloca las bases donde se fundamentan todas las representaciones del cosmos en la astronomía antigua.

Las consideraciones de un universo dotado de orden y armonía, llevaron por su parte a la escuela pitagórica a sostener que el *número* es el ente que vincula lo terrenal con lo divino pasando a ser el arché. Los planteamientos sobre los números, por parte de los pitagóricos, tuvieron importantes implicaciones en el desarrollo, no solo de las matemáticas, sino además en la cosmología ya que ponían de manifiesto la existencia de un patrón de lo divino en lo terrenal; un patrón que solo puede ser buscado mediante la introspección (Ruíz, 2003, p.39).

Con este tipo de ideas se empujaba el criterio de las matemáticas como aquello *perfecto e inmutable*, que daba cuenta de lo que *permanece* en el mundo dejando de lado el carácter empírico de la física. En su estudio “Teorías del universo” (2000) Pablo Melcon recoge como la escuela pitagórica establece el modelo de universo racional que define su cosmología al sostener que “[...] a la hora de mencionar los méritos de la cosmología pitagórica se aplaude haber aproximado la astronomía a la aritmética y a la geometría, pasando por la música” (2000, p. 804) El modelo cosmológico de los pitagóricos permite establecer una relación entre la estructura del mundo y las matemáticas sin distanciarse de las nociones estéticas como son la *belleza* y la *armonía* (entendiendo que la armonía se relaciona con las matemáticas a través de las proporciones, mostrado en la época moderna con las leyes de Kepler).

Esta aproximación conlleva a una comprensión del mundo a través de los sólidos regulares: tetraedro, octaedro, hexaedro, icosaedro etc., los cuales establecen una relación directa y armónica con los números. En su “Simetría: principio y método” (2001) sostiene José Cariñena: “la escuela pitagórica dejaba en claro la exigencia de la simetría o armonía como método para alcanzar la belleza: ¿Qué es lo más sabio? El número. ¿Qué es lo más bello? La armonía” (2001, p.11). La armonía de la que dan cuenta los números, además de su relación con los sólidos regulares, estaba fundamentada en su conmensurabilidad y, en tal sentido, sólo tenía relevancia los números enteros. Así, para los pitagóricos las fracciones no eran números: son entendidas como una razón entre dos números enteros y no una entidad numérica en sí misma (Ruíz, 2003, p.39-40) Un claro ejemplo lo otorgan los números irracionales, los cuales tampoco eran considerados como números ya que rompían con la *armonía* y la *belleza* establecida, es decir, no eran simétricos. La característica no simétrica, no bella o no armoniosa de los números irracionales se fundamenta en la imposibilidad de poder relacionarlos con la geometría y esta es la razón de que no fueran considerados números por la escuela pitagórica.

Estas consideraciones de los griegos, desde Thales hasta la escuela pitagórica, dibujan una definición implícita o indirecta de simetría que oscila entre la belleza —relacionada con aspectos como *orden*, *armonía* y *unidad*— y la matemática, especialmente la geometría, relacionándola con aspectos de *proporción*, *homogeneidad* e *isotropía*. En otras palabras, la perspectiva griega que carecía de término para aquello que hoy entendemos por simetría, relacionaba esta noción de manera tácita o implícita con ciertos aspectos estéticos y matemáticos. De aquí se desprende la primera distinción, siguiendo el estudio “Symmetries in Physics: Philosophical Reflections” de Katherine Branding y Elena Castellani (2003), de la noción de simetría en los griegos bajo el término de *simetría implícita*.

Ahora bien, debido a que la noción de *simetría implícita* refiere a aspectos estéticos y matemáticos podemos, en función de tales aspectos, distinguir dos acepciones más: a) desde lo estético, figurativo o contextual y b) desde las relaciones matemáticas o numéricas. Pasemos a atender la primera acepción: figurativa o contextual. La *simetría implícita* en su acepción figurativa subsume las nociones de *indiferencia, unidad, belleza, orden y armonía* de una forma *implícita*, permitiendo a los griegos clasificar las cosas en simétricas y no simétricas a través de cualidades y aspectos. Así pues, todo aquello que sea bello, armónico, ordenado, equilibrado está subsumido en la noción de *simetría implícita*, permitiendo discriminar qué es simétrico y que no.

Desde este punto de vista y en términos de Rudolph Carnap, la *simetría implícita* desde lo figurativo es un *concepto clasificatorio* (Moulines y Diez, 1997, p. 99) ya que discrimina las cosas a través de sus atributos lo que nos permite sostener, desde el punto de vista lógico, que la noción de simetría implícita figurativa es un predicado monádico (Moulines y Diez, 1997, p.99-100) Así mismo, podemos afirmar que la importancia de los atributos o cualidades de las cosas revela el uso de la noción de *simetría implícita figurativa* por parte de los griegos como *argumento*.

Ahora bien, la segunda acepción de simetría implícita viene dada a través de las *teorías de las proporciones y magnitudes*. Eudoxo de Cnido presenta *la teoría de las proporciones* con la finalidad de dar solución al problema de los irracionales: el objetivo era evitar el uso de los irracionales como números, sin dejar de hacer geometría, usando para ello la noción de *magnitud* (Ruíz, 2003, p.61) De esta forma, la noción de *magnitud* jugará un papel importante para la noción medieval de simetría. Recoge Ruíz que “para Eudoxo, una razón de magnitudes era una proporción [...] Tanto el concepto de razón como de proporción sólo tenían sentido en la geometría, no en la aritmética, porque no trataba de números [...] sobrepasando los aspectos críticos e inaceptables de los irracionales” (2003, p.61-62).

Eudoxo sostiene que los números son discretos, ya que se puede pasar de uno a otro mientras que las *magnitudes* son *continuas*. De esta forma las *magnitudes* son introducidas para tratar ángulos, segmentos, áreas, volúmenes que varían de una manera continua. Cuando dicha variación es una identidad entre dos razones, conmensurables o no, se tiene una relación entre magnitudes llamada proporción (Ruiz, 2003, p.61) Esta relación o proporción preserva, la armonía, la belleza y el equilibrio de las figuras geométricas. Con las ideas de Eudoxo la simetría implícita figurativa compartirá protagonismo con aquella simetría implícita que se relaciona con las nociones de equilibrio y equivalencia entre magnitudes, consecuencia de la teoría de las proporciones.

3. DE LA SUMMETRIA MEDIEVAL A LA SIMETRÍA MODERNA: EL TRÁNSITO DE LA PROPORCIÓN ARMÓNICA A LA INVARIANCIA TRANSFORMACIONAL

En la era medieval la simetría está vinculada a la perfección de Dios; la noción se entendía como proporcionalidad tanto en contextos matemáticos como en ámbitos estéticos (Hon y Goldstein, 2008, p. 1) Siguiendo a los griegos, los medievales asociaban la significación del término a un principio fundamental de orden, belleza y funcionalidad que debía atravesar todos los ámbitos del ser humano, y del mundo, lo que influyó en las reflexiones de la filosofía natural, la arquitectura y el arte (Hon y Goldstein, 2008, pp. 76-79).

Por ejemplo, desde el ámbito de la filosofía y la ciencia, pensadores como Boethius y Nicole Oresme entendían la simetría bajo la armonía de sistemas matemáticos y astronómicos (Hon y Goldstein, 2008, p. 79); mientras que, en la estética medieval, la noción de simetría se concibe como la conmensurabilidad de las partes con el todo, manifestando la perfección inefable de Dios en el mundo fenoménico (Eco, 2002, p. 58) Por su parte, Tomás de Aquino, uno de los pensadores más representativos de este periodo, sostenía que la belleza reside en la *debida proporción* ya que, el sentido se deleita en

lo *simétrico* por su similitud con la razón cognitiva vinculando así la estética a una experiencia intelectual y sensorial de lo armónico (Osborne, 1986, p. 78). Esta concepción de la simetría influyó en las artes figurativas y la arquitectura gótica, donde la simetría elevaba las obras al nivel matemático de la música, simbolizando la concordancia cósmica y la claridad luminosa como emanación divina (Eco, 2002, p. 55). De este modo, la simetría no era mero ornamento sino un vehículo teológico para la contemplación de lo eterno.

Pero, y a finales del siglo XIII, encontramos cambios en la significación de la noción. Esta transformación es recogida en *La Simetría* (1958) de Hermann Weyl quien hace referencia al *Deesis* de San Marco en Venecia. A diferencia de las obras medievales, en esta obra se asoman rasgos *asimétricos*. En palabras de Weyl:

La asimetría realizó nuevas incursiones en [...] una imagen bizantina del icono de San Marco, Venecia. Es el *Deesis*, [...] las dos figuras orando por misericordia cuando el Señor está a punto de pronunciar la última sentencia no pueden ser imágenes bilaterales el uno del otro ya que a la derecha se encuentra la Virgen Madre, a la izquierda Juan el Bautista. De igual manera se puede pensar en María y Juan el Evangelista en ambos lados de la cruz en las distintas representaciones de la crucifixión como ejemplos de la ruptura de simetría. Es evidente que la noción geométrica precisa de simetría bilateral comienza a disolverse en la vaga noción de *Ausgewogenheit* [...] Dondequiera que Dios o Cristo se representa como símbolo para la eterna verdad o la justicia se le da vista simétrica frontal. (Weyl, 1958, p.14)

Hay que entender que la *asimetría* no es *ausencia de simetría*. En el arte bizantino (tal como lo ejemplifica Weyl con el *Deesis* de San Marco) el *reposo* pasa a ser *volumétrico* (Weyl, 1958, p.14) ya que se muestra la similitud en el *peso de las imágenes* y no la *igualdad figurativa*. A esto, en ámbitos artísticos, se le denomina *equilibrio visual* (Castillo, 2018, p.22) Por sus características físicas a cada forma, proporción y textura se le puede asignar un determinado *peso visual* y, de acuerdo con su ubicación en el espacio y en relación con los pesos que se le contrapongan, su peso visual aumenta de valor, disminuye o se equilibra. Según esto, en el plano principal —digamos un lienzo en blanco—, se ubica el eje de simetría del espacio y los cuerpos —figuras de la composición—, gravitan en el espacio. El resultado compositivo puede ser equilibrado o desequilibrado, rígido o dúctil, simétrico o asimétrico (Castillo, 2018, p.22-23).

Sin embargo, el *Deesis*, asimétrico desde la perspectiva figurativa, gracias a la *igualdad de peso visual* es *simétrico* desde la perspectiva del volumen: Jesús es el eje que divide al lienzo en dos partes iguales; pero al colocar a María y a Juan a cada lado de Jesús aunque no son iguales figurativamente (*identidad substancial*) muestran igualdad en *peso visual (identidad esencial)* ya que ambos tienen la misma esencia (santidad). El movimiento está en una balanza imaginaria que muestra *igualdad de peso* desde la *identidad esencial* dando cuenta del equilibrio visual. Este movimiento de la balanza, refiere a la *equivalencia* entre los *pesos visuales* —magnitudes—, y como ambos tienen el mismo peso, entonces se mantiene el *equilibrio*, dando cuenta de la simetría, no desde lo figurativo, sino desde las relaciones (Castillo, 2018, p.23).

Aquí encontramos la segunda acepción o distinción de la noción de simetría a la que hacíamos referencia con las ideas de Eudoxo de Cnido. Pero no solo la estética muestra el tránsito de la noción desde su primera acepción a la segunda, podemos encontrar dicha transformación en otros ámbitos. En filosofía, por ejemplo, la paradoja del asno del teólogo escolástico Jean Buridan muestra como dos cosas distintas pero *indistinguibles* y *equivalentes* dan cuenta de la simetría en su segunda acepción (Ferrater Mora, 1970, p.62).

En el *Diccionario de Filosofía* de Ferrater Mora (1970) se recoge la paradoja de la siguiente manera: un asno que no sabe elegir entre dos montones de heno, y como consecuencia de ello termina muriendo de hambre. Se trata de una paradoja, ya que, pudiendo comer, no come porque no sabe, no puede o no quiere elegir qué montón es más conveniente, ya que ambos montones le parecen iguales (1970, p.62) Ahora bien, al ser *indistinto* o *equivalente* un montón del otro, se pueden intercambiar y el asno no notaría la diferencia. La *equivalencia* que hace *indistintos* ambos montones de heno da cuenta de la simetría no importando cuántas veces intercambiemos ambos montones el asno nunca se enterará del cambio. En el *Dessis* la *equivalencia* entre pesos visuales muestra la simetría en las relaciones; de manera análoga la paradoja de Buridan muestra la simetría cuando el asno no puede diferenciar un montón de otro (puesto que son equivalentes) después que se han intercambiado. En ciencia, si atendemos la concepción de espacio, podemos mostrar también la presencia de esta segunda acepción de la noción de *simetría*. En virtud de ello establezcamos primeramente algunos antecedentes previos de importancia.

Para Aristóteles, el espacio se identifica con el lugar definiéndose como frontera o límite adyacente al cuerpo continente (Jammer, 1970, p.79). Con las ideas de Telesio y Gassendi se da un viraje. Bernardino Telesio, adoptó conceptos materialistas y estoicos de la Antigüedad que le llevaron a dotar de realidad independiente el espacio (Jammer, p.116) Así el espacio vacío es algo capaz de contener cuerpos pudiendo existir sin estos: es aquello en que los cuerpos pueden ocupar. Por su parte Pierre Gassendi sostiene el espacio *infinito* y *coeterno* con Dios y lo define por su extensión como un dato de tres dimensiones, distinguiendo entre dos tipos de extensión: una llena (cuerpo) y otra vacía (espacio) (Del Pozo, 1997, p.89).

Para Gassendi el espacio es *necesario, infinito, inmóvil e incorpóreo*, advirtiendo que no es una ficción, atributo o modo de la sustancia (Jammer, p.125) estando además el espacio vacío permeado de fuerzas, colmado de virtudes y presencia divina. Las características atribuidas al espacio por Telesio y Gassendi —*homogéneo, isótropo y uniforme*— como *argumentos* de *simetría* revelan que las descripciones del mundo para los medievales responden a un principio *isotrópico, homogéneo, uniforme, ordenado, bello y armonioso*. Es así como, de las ideas de Telesio y Gassendi, se muestra como los *argumentos* de simetría que describen el espacio pasan a ser *principio* de simetría donde se fundamentan las descripciones del mundo.

Pero lo cierto es que el mundo está en movimiento y en constante cambio, aunque dentro de esa vorágine de cambios debe permanecer subyacente el principio *isotrópico, homogéneo, uniforme, ordenado, bello y armonioso*. Entonces, si bien se sabe que lo que cambia no puede ser descrito, y el mundo de hecho cambia, entonces ¿qué es aquello *inmutable* que permite describir al mundo bajo una concepción *armónica, bella y ordenada*? Para los renacentistas lo que da cuenta del *orden* y *armonía* del mundo en movimiento son las leyes que *permanecen invariantes* frente al cambio. Ruiz recoge que en “el siglo XV, una de las principales influencias fueron las obras de Platón: el diseño matemático de la naturaleza, que incorporaba las características de armonía, verdad y belleza. La naturaleza es descrita entonces a través de leyes inmutables dentro de una comprensión que es racional y estructurada” (Ruiz, p.191).

La idea del mundo en movimiento dirigido por un Ser divino e inteligente, que garantiza el *orden, la belleza y la armonía* del mundo, inspirará a pensadores como Copérnico, Galileo, Kepler, Newton o Leibniz a describir la realidad integralmente en forma de leyes de la naturaleza bajo los supuestos anteriores. De esta forma, mientras que para los griegos la armonía, belleza y orden son *argumentos*, para los modernos son *principio* presente en las leyes.

Copérnico coloca el Sol como centro de un universo *indiferente o isótropo*, es decir, *simétrico* manteniendo las órbitas de los planetas circulares. Sobre tales aspectos —isotropía y órbita circular— o *argu-*

mentos de simetría, Copérnico da cuenta de la *perfección, armonía y orden* entre los orbes del universo, es decir, da cuenta del *principio* de simetría. Sin embargo, los datos obtenidos por Tycho Brahe presentaban discrepancia con las trayectorias concéntricas de Copérnico. Las leyes de Kepler pasan a solventar la discordancia entre teoría y mundo bajo la teoría de las proporciones de Eudoxo, mostrándose de esta manera la segunda acepción de simetría implícita a través de las relaciones entre magnitudes equivalentes. En su tercera ley, Kepler establece la *armonía* del mundo (principio de simetría) como una *relación proporcional* entre magnitud (*periodo*) y trayectoria elíptica (semieje mayor). De esta manera, Kepler describe un mundo armónico mediante sus leyes que dan cuenta de relaciones proporcionales entre los planetas, introduciendo implícitamente la *simetría* en su segunda acepción.

Otra importante contribución es el *Principio de Relatividad Galileano o Invariancia Relativista* que refiere a la imposibilidad de determinar el movimiento real de la Tierra mirando solo de manera local los fenómenos que nos rodean. El ejemplo que ofrece Galileo, en *Dialogo sopra i due massimi sistemi del mondo* es recogido por S. Drake en su obra *Dialogue concerning the two chief world systems. Ptolemaic & Copernican* (1967) en la página 186 y trata de la analogía con la cabina de un barco. En palabras de Galileo:

Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it no more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully (though there is no doubt that when the ship is standing still everything must happen in this way), have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still [...] The cause of all these correspondences of effects is the fact that the ship's motion is common to all the things contained in it, and to the air also. That is why I said you should be below decks; for if this took place above in the open air, which would not follow the course of the ship, more or less noticeable differences would be seen in some of the effects noted.. (Galileo, 1967, p.186)

Galileo, siguiendo a Telesio y Gassendi, otorga al espacio las propiedades de *uniformidad, homogeneidad e isotropía* (argumentos de simetría), estableciendo el espacio como *simétrico* en función de esas características (principio de simetría). El toscano establece su *principio de relatividad o invariancia*, en el que está presente la dicotomía entre lo aparente y lo verdadero, lo absoluto y lo relativo, etc., siendo justamente las propiedades del espacio las que explicarían los límites de la percepción para distinguir entre el movimiento y el reposo.

Reposo y movimiento uniforme son estados de movimientos *distintos, indistinguibles y equivalentes*. La explicación científica de la indistinción perceptiva entre los estados de movimiento estará dada por la *equivalencia* entre sus *magnitudes*.

En el ejemplo del *Dessis*, se establecía la *equivalencia* entre *pesos visuales —magnitudes—* y no entre las figuras —*Juan no es igual a María—*, de igual forma, aunque los estados de movimiento —*reposo y movimiento uniforme—* no son iguales mantienen una *equivalencia* entre sus magnitudes —*velocidad—*. En otras palabras: lo que asoma el *equilibrio* en el *Dessis* no son las figuras, sino la *equivalencia* entre los *pesos visuales*. Del mismo modo, en la paradoja de Buridan, el *equilibrio* está

dado en la *equivalencia* entre ambos montones de heno que los hace *indistinguibles* para el asno. En el caso de la física, lo que asoma el *equilibrio* en la indistinción entre movimientos inerciales, no es el reposo versus movimiento, sino la *equivalencia* entre sus *velocidades*. La velocidad es constante en ambos, pero su valor es distinto en cada uno (reposo tiene velocidad constante nula); luego son *equivalentes* en magnitud, pero no iguales. La indistinción entre estados de movimientos, que lleva a la *equivalencia* entre las *magnitudes* da cuenta de la *simetría* en términos *equilibrio* y *equivalencia* (Brading y Castellani, 2003, p.6).

Telesio y Gassendi describen el espacio a través de los aspectos de homogeneidad, uniformidad e isotropía siendo, en este caso, argumento de simetría. Sin embargo, tales *argumentos* pasan a convertirse en *principio* de simetría, en términos aristotélicos, dentro de la *invariancia relativista* del toscano, al considerar que la descripción del mundo debe hacerse bajo los aspectos de *homogeneidad*, *uniformidad* e *isotropía*. Esto muestra, dos problemáticas en torno a la noción de simetría: 1) en cuanto a su distinción entre implícita y explícita, y 2) la oscilación de la noción como argumento o como principio dentro de una teoría.

Podemos resumir diciendo que la *simetría* en la antigüedad es entendida como *cualidad* o *aspecto* que muestra *armonía*, *orden* y *belleza*. Ésta visión estética, que permite comprender la noción de simetría implícita figurativa o contextual como concepto clasificatorio, tendrá cierta influencia en la época moderna al considerar los aspectos o atributos del espacio; muestra de ello son las ideas de Galileo, las cuales además dan cuenta del cambio en el uso de la noción por parte de la física, al considerar los atributos del espacio, entendidos como argumentos de simetría, como principio de simetría al exigirse que todas las descripciones de la filosofía natural deben fundarse en tales aspectos del espacio. En otras palabras, las ideas de Galileo muestran como los argumentos de simetría pasan a ser principios de simetría.

Ahora bien, además del uso de la noción de simetría como principio y argumento, dentro de la reconstrucción hemos distinguido dos nociones de *simetría* las cuales son *implícitas*: una antigua que viene dada como *aspecto* o *cualidad de la cosa* bajo las nociones de *armonía*, *orden* y *belleza*; y una visión *moderna*, iniciada por Eudoxo de Cnido, presente en el arte medieval, y que Galileo amplía con los conceptos de *indistinción*, *invariancia*, *equilibrio* y *equivalencia*, bajo la consideración de las relaciones equivalentes entre movimiento y reposo en el principio galileano. Siendo ambas acepciones conceptos clasificatorios.

4. CONCLUSIONES

La noción de simetría revela una evolución profunda en su significación y uso, que ilustra cambios en su función epistemológica dentro del conocimiento científico.

Desde los griegos, la simetría opera como argumento, en tanto atributo de la cosa, siendo la indiferencia, armonía, belleza, orden, y equilibrio, indicios de la noción. En la astronomía medieval, la noción experimenta un giro: pasa de ser argumento a principio. Aquí, la simetría no solo describe una propiedad observada, sino que actúa como principio ordenador reflejando un orden divino y proporcional. En la era moderna la simetría adquiere una nueva significación marcando la transición definitiva hacia un uso explícito y sistemático de la simetría como principio heurístico y axiomático en las teorías físicas. Este estudio ha clasificado la noción de simetría siguiendo los esquemas de: a) principio-argumento (John Roche); b) implícita-explicita sostenida por Katherine Brading y Elena Castellani; c) figurativa-normativa bajo el sistema de clasificación de Carnap y Moulines. Estas distinciones invita a reflexionar sobre el anacronismo historiográfico y la riqueza de las reconstrucciones conceptuales en la filosofía de la física.

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Artificial Intelligence, Digital Transformation and Contemporary Challenges / Inteligencia Artificial, Transformación Digital y desafíos contemporáneos

The volume *Artificial Intelligence, Digital Transformation and Contemporary Challenges* offers an interdisciplinary approach to the challenges and opportunities arising from artificial intelligence (AI) and digital transformation in contemporary society. Through a range of contributions, the book examines the impact of these technologies on fields such as education, healthcare, and human development, while also incorporating historical and philosophical perspectives that contextualise current technological changes.

The first section analyses the growing integration of digital and algorithmic systems within educational environments. The chapters address issues related to the transformation of educational systems, the adoption of emerging technologies in higher education, teachers' AI literacy, and the development of students' digital competences. Furthermore, innovative pedagogical approaches, including co-teaching and social robotics, are examined, together with the consequences of the COVID-19 pandemic in accelerating processes of educational digitalisation.

The second section focuses on the relationship between technology, health, and ethics. Particular attention is given to the potential of artificial intelligence to enhance diagnostic procedures, patient monitoring, and healthcare treatment planning, while emphasising the need to uphold ethical principles concerning privacy, equity, accountability, and human oversight. In addition, a discussion of the Mediterranean diet to a broader understanding of human wellbeing from an interdisciplinary perspective.

The final section provides a historical and philosophical perspective on the evolution of scientific and mathematical concepts, situating contemporary technological developments within a wider intellectual tradition. Taken together, the volume demonstrates that technological progress requires responsible governance and sustained ethical reflection, reaffirming the importance of human-centred approaches in addressing the challenges of digital transformation.

La obra *Inteligencia Artificial, Transformación Digital y desafíos contemporáneos* ofrece una aproximación interdisciplinar a los desafíos y oportunidades derivados de la inteligencia artificial (IA) y la transformación digital en la sociedad contemporánea. A través de diversas contribuciones, el volumen examina el impacto de estas tecnologías en ámbitos como la educación, la salud y el desarrollo humano, incorporando además perspectivas históricas y filosóficas que permiten contextualizar los cambios tecnológicos actuales.

La primera sección analiza la creciente integración de sistemas digitales y algorítmicos en los entornos educativos. Los capítulos abordan cuestiones relacionadas con la transformación de los sistemas educativos, la incorporación de tecnologías emergentes en la educación superior, la alfabetización en inteligencia artificial del profesorado y el desarrollo de las competencias digitales del alumnado. Asimismo, se examinan modelos pedagógicos innovadores, como la codocencia y la robótica social, así como las consecuencias de la pandemia de COVID-19 en la aceleración de los procesos de digitalización educativa.

La segunda sección se centra en la relación entre tecnología, salud y ética. Se destacan las posibilidades de la inteligencia artificial para mejorar los procesos de diagnóstico, monitorización y tratamiento sanitario, al tiempo que se subraya la necesidad de garantizar principios éticos relacionados con la privacidad, la equidad, la responsabilidad y la supervisión humana. Además, se incorpora una reflexión sobre la dieta mediterránea como elemento fundamental para la comprensión integral del bienestar humano.

Finalmente, la tercera sección aporta una perspectiva histórica y filosófica sobre la evolución de los conceptos científicos y matemáticos, situando los desarrollos tecnológicos contemporáneos dentro de una tradición intelectual más amplia. En conjunto, la obra pone de manifiesto que el progreso tecnológico requiere una gobernanza responsable y una sólida reflexión ética, reaffirmando la importancia de enfoques centrados en las personas para afrontar los desafíos de la transformación digital.