

UNIVERSIDADE NOVE DE JULHO – UNINOVE
PROGRAMA DE PÓS-GRADUAÇÃO EM INFORMÁTICA
E GESTÃO DO CONHECIMENTO

EMILIA AUGUSTA REGO

ELEMENTS OF EDUCATION 4.0 AS SUPPORT FOR PROMOTING
EDUCATION 5.0 IN TECHNOLOGICAL HIGHER EDUCATION
INSTITUTIONS

São Paulo
2026

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Dissertação de mestrado apresentada ao Programa de Pós-Graduação em Informática e Gestão do Conhecimento da Universidade Nove de Julho - UNINOVE, como requisito parcial para obtenção do título de Mestre.

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ATA DE DEFESA DA DISSERTAÇÃO

Ao vigésimo oitavo dia do mês de janeiro de dois mil e vinte e seis, às 10h00, no Programa de Pós-Graduação desta Universidade, reuniu-se em sessão pública a Comissão Julgadora da dissertação de mestrado de Emilia Augusta Rego, sob o título "ELEMENTS OF EDUCATION 4.0 AS SUPPORT FOR PROMOTING EDUCATION 5.0 IN TECHNOLOGICAL HIGHER EDUCATION INSTITUTIONS". Integraram a comissão os professores Doutores: Marcos Antonio Gaspar (UNINOVE), Andréa Paiva Gonçalves Reinstein (FIAP) e Ivanir Costa (UNINOVE), sob a presidência do primeiro, orientador da dissertação. A banca examinadora, tendo decidido aceitar a dissertação, passou à arguição pública da candidata. Encerrados os trabalhos, os examinadores deram parecer final sobre a dissertação.

	Parecer
Prof. Dr. Marcos Antonio Gaspar	Aprovada
Profa. Dra. Andréa Paiva Gonçalves Reinstein	Aprovada
Prof. Dr. Ivanir Costa	Aprovada

Parecer:

Aprovada.

Em conclusão, a candidata foi considerada APROVADA, no grau de Mestra em Informática e Gestão do Conhecimento. E, para constar, eu, Prof. Dr. André Felipe Henriques Librantz, diretor do Programa de Mestrado e Doutorado em Informática e Gestão do Conhecimento, lavrei a presente ata que assino juntamente com os membros da banca examinadora.

São Paulo, 28 de janeiro de 2026.

Prof. Dr. Marcos Antonio Gaspar

Profa. Dra. Andréa Paiva Gonçalves
Reinstein

Prof. Dr. Ivanir Costa

Prof. Dr. André Felipe Henriques Librantz

I dedicate this work to the memory of my parents, José and Natividade, who were my foundation and my greatest inspiration in life. Although they are no longer with me, they live on in my values, my journey, and everything I have become.

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*“Education is the most powerful weapon
which you can use to change the world.”*

Nelson Mandela

ABSTRACT

The rapid advancement of digital technologies is accelerating educational transformation worldwide while also deepening disparities in developing countries, where infrastructure and educator training remain uneven. This context reinforces the transition from Education 4.0, which emphasizes digitalization and automation, toward Education 5.0, characterized by human-centered, AI-supported, and sustainability-oriented learning ecosystems. In Brazil, Technological Higher Education Institutions (THEIs) continue to face persistent barriers to this transition, including limited Information and Communication Technology (ICT) resources, insufficient digital readiness, and unequal access to emerging technologies. The objective of this research is to identify and characterize the main elements of current Education 4.0 frameworks that could facilitate the adoption of Education 5.0 in Brazilian THEIs. This study adopts a qualitative, exploratory-descriptive design, developed through a Systematic Literature Review (SLR) that analyzed five consolidated Education 4.0 frameworks, followed by validation by three experts. The empirical phase included 54 PhD professors and researchers from 32 federal, state, private, and community THEIs across 14 Brazilian states. Data were collected through structured questionnaires combining Likert-type evaluation and open-ended questions, enabling refinement of the proposed elements. The results validate three dimensions—Technology, Skills, and Innovation—comprising a total of 35 elements identified, refined, and approved by the expert committee. The Technology dimension includes 13 elements, with highly rated components such as Responsible and Sustainable Tech Training, AI Literacy and Computational Thinking, Smart Infrastructure for Adaptive and Technology-Enhanced Learning, High-Speed Networks, and AI-Enhanced Ecosystems. The Skills dimension consists of 10 elements, emphasizing Analytical and Critical Thinking, Socioemotional Competencies, Cognitive and Socioemotional Skills for 21st-Century Professionals, Integration of Human and Technical Skills, and Complex Problem-Solving. The Innovation dimension contains 12 elements, highlighting Reflective and Collaborative Teaching, Inclusion, Sustainability and Societal Impact, Problem-Based and Scenario-Based Learning, Technology-Enhanced Learning Analytics, and Neuroscience. In conclusion, the three validated dimensions and 35 elements constitute a foundational theoretical structure to support the evolution of Education 5.0 in Technological Higher Education Institutions in Brazil. As a contribution to academia, this study advances the literature by consolidating, organizing, and validating key elements from Education 4.0 frameworks into a structured and empirically supported set of elements aligned with Education 5.0 principles. As a contribution to practitioners and society, the findings provide evidence-based guidance for institutional leaders and educators to strengthen digital transformation strategies, improve teacher development, and promote more equitable, ethical, and sustainable learning environments.

Keywords: digital transformation; education 4.0; education 4.0 framework; education 5.0; artificial intelligence.

RESUMO

O rápido avanço das tecnologias digitais vem acelerando a transformação educacional em escala global, ao mesmo tempo em que aprofunda desigualdades em países em desenvolvimento, nos quais a infraestrutura e a formação docente permanecem heterogêneas e insuficientes. Esse cenário reforça a transição da Educação 4.0, que enfatiza a digitalização e a automação, para a Educação 5.0, caracterizada por ecossistemas de aprendizagem centrados no ser humano, apoiados por Inteligência Artificial (IA) e orientados à sustentabilidade. No Brasil, as Instituições de Ensino Superior Tecnológico (IESTs) continuam a enfrentar barreiras persistentes para essa transição, incluindo recursos limitados de Tecnologias da Informação e Comunicação (TIC), baixa prontidão digital e acesso desigual a tecnologias emergentes. O objetivo desta pesquisa é identificar e caracterizar os principais elementos de frameworks contemporâneos de Educação 4.0 que possam facilitar a adoção da Educação 5.0 em IESTs brasileiras. O estudo adota um delineamento qualitativo, exploratório-descritivo, desenvolvido por meio de uma Revisão Sistemática da Literatura (RSL), que analisou cinco frameworks consolidados de Educação 4.0, seguida de validação por três especialistas. A fase empírica contou com 54 professores e pesquisadores doutores, vinculados a 32 IESTs federais, estaduais, privadas e comunitárias, distribuídas em 14 estados brasileiros. Os dados foram coletados por meio de questionários estruturados, combinando avaliação do tipo Likert e questões abertas, possibilitando o refinamento das dimensões e dos elementos propostos. Os resultados validam três dimensões, Tecnologia, Competências e Inovação, totalizando 35 elementos identificados, refinados e aprovados pelo comitê de especialistas. A dimensão Tecnologia contempla 13 elementos, com componentes altamente avaliados, tais como Formação em Tecnologia Responsável e Sustentável, Letramento em IA e Pensamento Computacional, Infraestrutura Inteligente para Aprendizagem Adaptativa e Apoiada por Tecnologias, Redes de Alta Velocidade e Ecossistemas Aprimorados por IA. A dimensão Competências é composta por 10 elementos, enfatizando Pensamento Analítico e Crítico, Competências Socioemocionais, Competências Cognitivas e Socioemocionais para Profissionais do Século XXI, Integração entre Competências Humanas e Técnicas e Resolução de Problemas Complexos. A dimensão Inovação reúne 12 elementos, destacando Docência Reflexiva e Colaborativa, Inclusão, Sustentabilidade e Impacto Social, Aprendizagem Baseada em Problemas e em Cenários, Learning Analytics Potencializada por Tecnologias e Neurociência. Conclui-se que as três dimensões validadas e os 35 elementos constituem uma estrutura teórica fundamental para apoiar a evolução rumo à Educação 5.0 nas Instituições de Ensino Superior Tecnológico no Brasil. Como contribuição à academia, este estudo avança a literatura ao consolidar, organizar e validar elementos-chave provenientes de frameworks de Educação 4.0 em um conjunto estruturado e empiricamente sustentado, alinhado aos princípios da Educação 5.0. Como contribuição para profissionais e para a sociedade, os achados oferecem orientações baseadas em evidências para gestores institucionais e educadores, com vistas a fortalecer estratégias de transformação digital, aprimorar o desenvolvimento docente e promover ambientes de aprendizagem que sejam mais equitativos, éticos e sustentáveis.

Palavras-chave: transformação digital; educação 4.0; modelo de educação 4.0; educação 5.0; inteligência artificial.

Acronyms List

Acronyms	Definition
4IR	Fourth Industrial Revolution
AI	Artificial Intelligence
AR	Augmented Reality
CEETEPS	Centro Estadual de Educação Tecnológica Paula Souza
CEFET-MG	Centro Federal de Educação Tecnológica de Minas Gerais
DEEs	Digital Education Ecosystems
DL	Deep Learning
DT	Digital Transformation
Education 4.0	The fourth generation of education
Education 5.0	The fifth generation of education
FATEC	Faculdade de Tecnologia do Estado de São Paulo
FGV-SP	Fundação Getulio Vargas – São Paulo
GenAI or GAI	Generative Artificial Intelligence
ICT	Information Communication Technology
IF Goiano	Instituto Federal Goiano
IF Sudeste MG	Instituto Federal do Sudeste de Minas Gerais
IFAC	Instituto Federal do Acre
IFAL	Instituto Federal de Alagoas
IFB	Instituto Federal de Brasília
IFBA	Instituto Federal da Bahia
IFC	Instituto Federal Catarinense
IFES	Instituto Federal do Espírito Santo
IFF	Instituto Federal Fluminense
IFMA	Instituto Federal do Maranhão
IFMS	Instituto Federal de Mato Grosso do Sul
IFPR	Instituto Federal do Paraná
IFRJ	Instituto Federal do Rio de Janeiro
IFRS	Instituto Federal do Rio Grande do Sul
IFS	Instituto Federal de Sergipe
IFSP	Instituto Federal de São Paulo
IFSul	Instituto Federal Sul-rio-grandense
IFTM	Instituto Federal do Triângulo Mineiro
IFTO	Instituto Federal do Tocantins
IIoT	Industrial Internet of Things
INPI	Instituto Nacional da Propriedade Industrial

IoT	Internet of Things
LMS	Learning Management Systems
ML	Machine Learning
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SDGs	Sustainable Development Goals
SLR	Systematic Literature Review
STEM	Science, Technology, Engineering, Mathematics
TADEO	Digital transformation in Education (Portuguese: Transformação Digital na Educação)
THEIs	Technological Higher Education Institutions
UFC	Universidade Federal do Ceará
UFPR	Universidade Federal do Paraná
UNEMAT	Universidade do Estado de Mato Grosso
UNIARA	Universidade de Araraquara
UNIJUÍ	Universidade Regional do Noroeste do Estado do Rio Grande do Sul
UNINOVE	Universidade Nove de Julho
UNINTER	Centro Universitário Internacional
USCS	Universidade Municipal de São Caetano do Sul
WA	Weighted Average
WEF	World Economic Forum

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1. INTRODUCTION

This chapter presents the concept of Digital Transformation (DT) and its significant impact on education, tracing the shift from traditional Education 1.0 models to the emerging paradigm of Education 5.0. It explores how DT is reshaping Technological Higher Education Institutions (THEIs) in developing countries through advanced technologies such as Artificial Intelligence (AI), and more recently, Generative Artificial Intelligence (GenAI). These tools enable more human-centered, adaptive, and inclusive learning environments; even in contexts challenged by limited infrastructure and gaps in educator training. The chapter also presents how DT enhances institutional processes, drives innovation, and addresses global educational challenges, particularly by promoting personalized learning and data-driven decision-making.

Additionally, it examines the transition from teacher-centered methodologies to student-centered, technology-mediated models typical of Education 4.0 and 5.0, in alignment with the broader objectives of Industry 4.0 and 5.0. Moreover, the chapter identifies research gaps and outlines research objectives to advance Education 5.0 within Brazilian THEIs. It emphasizes the need for better infrastructure, comprehensive teacher development, and strategies to ensure equitable access to education. The chapter is organized into the following sections: contextualization, identification of research gaps and formulation of research questions, research objectives, study justification, and scope definition.

1.1. Contextualization

Digital Transformation (DT) has emerged as an important phenomenon of the 21st century, reshaping how societies function and organizations operate. According to Vial (2019, p. 118–144), DT can be conceptualized as “a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies.” This definition underscores how digital technologies fundamentally alter organizational processes, structures, and interactions, enhancing efficiency, fostering innovation, and enabling responsiveness to global demands. The COVID-19 pandemic accelerated the adoption of digital solutions, driving organizations toward resilience

and operational continuity (Benavides *et al.*, 2020). UNESCO (2021) emphasizes that digital technologies should promote human rights, strengthen capabilities, and support collective action for peace, justice, and sustainability, recognizing digital access as a basic right essential for civic and economic participation.

In education, DT has significantly transformed teaching and learning, redefining the roles of institutions, administrators, teachers, and students. As García-Morales *et al.*, (2021) highlight, DT expands accessibility and personalizes learning, empowering institutions to surpass traditional boundaries and cater to diverse student needs. Moreover, it streamlines management and promotes data-driven decision-making, enabling administrators to optimize resources, supporting teachers in adopting innovative pedagogies, and equipping students with vital digital competencies (Benavides *et al.*, 2020). Within this transformation, Generative Artificial Intelligence (GenAI) emerges as a key enabler, particularly in education, where it enhances adaptive learning, supports personalized content creation, and fosters collaborative and interactive learning environments, reshaping education in line with Education 4.0 principles while raising new ethical and pedagogical considerations (Guettala *et al.*, 2024; Peláez-Sánchez *et al.*, 2024; Sandhu *et al.*, 2024).

While Generative AI tools present a set of both challenges and opportunities, it is important for educational bodies and institutions to remain vigilant and proactive in observing and governing the use of such tools, especially considering that some countries and school systems have moved to ban tools such as ChatGPT in classrooms. (Lim *et al.*, 2023) In this context, governance and strategic regulation may be more effective than prohibition alone, since bans can unintentionally increase interest and use among students.

It is important to consider that education is universally recognized as a fundamental human right and a cornerstone of societal advancement (Felcher *et al.*, 2022; Maria *et al.*, 2021). The effective dissemination of knowledge has long been a key metric of progress. However, the past decade has witnessed a seismic shift in educational paradigms, driven by the rapid expansion of digital technologies and advancements in Information and Communication Technology (ICT). These developments, coupled with the integration of sensor-based technologies and AI-driven data processing, have laid the foundation for next-generation educational frameworks (Agarwal *et al.*, 2025; Ahmad *et al.*, 2023). This technological evolution has fundamentally reshaped global education systems, shifting from conventional,

teacher-centric approaches to dynamic, technology-enhanced learning environments. UNESCO (2021) describes this phenomenon as a future-ready 'Education 5.0' paradigm, where technology enhances inclusive and equitable learning.

The evolution of education from Education 1.0 to Education 4.0 reflects a transformative journey driven by technological and pedagogical shifts. Education 1.0, as described by Pooworawan (2015), represents the pre-digital era, characterized by a teacher-centered approach that relies heavily on textbooks and rote memorization, with minimal use of technology. Education 2.0 marks the early integration of digital tools, such as blogs and Web 2.0 technologies, enhancing collaboration while remaining largely teacher-focused (Puncreobutr, 2016). Education 3.0 shifts toward student-centered learning, leveraging digital platforms and Learning Management Systems (LMS) to enable self-directed exploration, with educators acting as facilitators (OECD, 2019).

Education 4.0, aligned with Industry 4.0, emphasizes digitalization, artificial intelligence (AI), and immersive technologies such as virtual reality (VR) and augmented reality (AR) to foster 21st-century skills like creativity and problem-solving (Chituc, 2022a). Well-established Education 4.0 frameworks in academic research include Digital Education Ecosystems (DEEs)(Chituc, 2022a), the Malaysian Higher Education 4.0 Framework, (Kolandan, 2019), STEM Learning (Falloon *et al.*, 2020), TADEO (Oliveira & de Souza, 2021), and the World Economic Forum (WEF) Education 4.0 Framework (WEF, 2023).

While the goal of Education 4.0 is to align education with the technological advancements adopted by society and its different agents, creating stronger engagement with new generations who are deeply integrated with technology (Carvalho, 2023), Education 5.0 builds upon this foundation. It does not replace the principles of Education 4.0; rather, it expands them by adopting a more human-oriented perspective, emphasizing competencies related to collaboration, well-being, and responsible participation in learning environments. In addition, Education 5.0 reinforces concerns related to sustainability as well as health and safety within educational contexts (Carvalho, 2023; Rahim, 2021; Singh *et al.*, 2023). However, it is important to highlight that this study does not aim to explore these aspects in depth, since its scope is deliberately delimited to the context of Technological Higher Education Institutions (THEIs) and to the analysis of Education 4.0 frameworks as support for Education 5.0, focusing on the dimensions investigated in this research.

At the forefront of this transformation is Education 5.0, the fifth generation of education, which aligns seamlessly with the human-centric, technology-driven ethos of Industry 5.0. Education 5.0 integrates AI, ICT, and personalized learning ecosystems to foster innovation, adaptability, and lifewide learning (Rahim, 2021). In Technological Higher Education Institutions (THEIs) - encompassing universities, colleges, and technical schools, this shift offers transformative potential. By merging cutting-edge technologies with student-centered pedagogies, Education 5.0 equips learners with critical 21st-century skills, including critical thinking, digital literacy, and problem-solving, preparing them for the demands of an increasingly interconnected and AI-dominated workforce (Ahmad *et al.*, 2023; Alharbi, 2023; Singh *et al.*, 2023).

Despite its promise, the global adoption of Education 5.0 remains uneven. In many contexts, persistent institutional and infrastructural shortcomings can intensify the risks associated with the indiscriminate use of Generative AI in academic environments, particularly when clear policies, educator training, and ethical guidance are still lacking. This concern aligns with UNESCO's warnings that the education sector is not yet adequately prepared to integrate AI responsibly, reinforcing the need for governance frameworks and structured implementation rather than uncontrolled adoption (Martins, 2025). Developing countries, in particular, encounter substantial obstacles that impede its implementation (Agarwal *et al.*, 2025; Rahim, 2021). These challenges are especially pronounced in emerging economies, particularly within Technological Higher Education Institutions (THEIs), where diverse educators are pivotal in driving this transition. The Brazilian educational system highlights the necessity of advancing Education 5.0 to meet 21st-century workforce demands through digital technologies and active methodologies, yet challenges such as outdated infrastructure and insufficient teacher training impede effective implementation (Maria *et al.*, 2021; Souza & Medeiros Neta, 2021).

1.2. Identification of gaps and research questions

The global education technology market is set for significant growth, with a projected compound annual growth rate of 17% between 2021 and 2025 (Ahmad *et al.*, 2023). Education 5.0 is increasingly recognized as essential for preparing students for AI-driven industries. However, a stark disparity remains: 72% of higher education institutions in developing nations lack foundational ICT infrastructure (WEF, 2023).

This gap is particularly evident in Brazil, specifically in São Paulo city and its neighboring regions, a key economic hub that accounts for 32% of the country's GDP but lags in educational innovation (IBGE, 2024). These systemic challenges highlight the urgent need for targeted research into DT within THEIs.

While Education 4.0 has been adopted worldwide, Education 5.0's emergence requires further research, particularly regarding how it builds upon and extends Education 4.0 principles. Education 4.0, as described by Chituc (2022a), represents a transformative paradigm aligned with Industry 4.0, emphasizing the integration of advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and immersive tools like virtual reality (VR) and augmented reality (AR). These technologies foster 21st-century skills, including creativity, problem-solving, and digital literacy. Existing frameworks, such as Digital Education Ecosystems (DEEs), the Malaysian Higher Education 4.0 Framework, STEM Learning, TADEO, and the World Economic Forum (WEF) Education 4.0 integrates digital technologies and active methodologies to foster innovative pedagogical practices and personalized learning, laying a robust foundation for contemporary education (Felcher *et al.*, 2022; Maria *et al.*, 2021)

However, the emergence of Education 5.0, as highlighted by (Rahim, 2021), introduces a more human-centric and technology-driven approach that prioritizes social-emotional skills, sustainability, and lifelong learning. This shift necessitates a reevaluation of existing frameworks. While Education 4.0 frameworks are well-established, their adaptation to incorporate emerging ICT trends and AI advancements remains underexplored, particularly in developing regions (Chituc, 2022a). Similarly, Rahim (2021) argues that transitioning to Education 5.0 requires new research on how existing frameworks can support seamless human-technology synergy, especially in resource-constrained settings. Education 4.0 frameworks, while advanced, require ongoing research and adaptation to address the dynamic needs of emerging educational paradigms like Education 5.0, which emphasize human-centric and socioemotional competencies alongside technological integration (Chituc, 2022a)

Although Education 5.0 has been studied in various contexts, significant gaps remain in understanding its implementation in developing countries, particularly in higher technology education. Existing studies compare successful implementations in countries like Saudi Arabia and Malaysia with struggling cases in Zimbabwe and Sri Lanka (Alharbi, 2023). However, these analyses often lack detailed insights into

regional dynamics within developing nations. The integration of digital technologies in Brazilian educational systems, particularly in terms of infrastructure, teacher training, and equitable access, remains insufficiently addressed, highlighting a significant research gap in achieving Education 4.0 and 5.0 standards (Oliveira & de Souza, 2021).

Additionally, the frameworks of Education 4.0 provide a foundational roadmap for developing countries seeking to implement Education 5.0, emphasizing the necessity for tailored approaches that address local challenges and maximize technological potential. The transition from Education 4.0 to Education 5.0 represents a pivotal evolution in educational paradigms, shifting from a technology-centric model aligned with Industry 4.0 to a human-centric, technology-enhanced framework resonant with Industry 5.0 (Felcher *et al.*, 2022). Education 4.0, characterized by digitalization, artificial intelligence (AI), and immersive technologies, has laid a robust foundation for modern education systems globally. Education 5.0 builds upon this by emphasizing social-emotional skills, sustainability, and lifelong learning, integrating advanced ICT and AI to foster innovation and adaptability (Rahim, 2021; Singh *et al.*, 2023). However, the adoption of Education 5.0 in Technological Higher Education Institutions (THEIs) in developing countries, faces significant challenges, including inadequate infrastructure, limited educator capacity, and access disparities (Agarwal *et al.*, 2025).

Much of the current academic articles and literature researched for this dissertation focus on Education 4.0 frameworks, which emphasize digitalization and automation but fall short of addressing the human-technology synergy central to Education 5.0. This misalignment highlights a further gap: the absence of an adaptable framework tailored to the unique challenges of Education 5.0 in resource-constrained settings. Consequently, this study poses the following research question:

Which elements of current Education 4.0 frameworks could facilitate the adoption of Education 5.0 in Technological Higher Education Institutions in Brazil?

1.3. Research objectives

A key objective is to identify and characterize the main elements of current Education 4.0 frameworks that could facilitate the adoption of Education 5.0 in Technological Higher Education Institutions in Brazil.

To achieve this, the study pursues the following specific objectives:

- (I) To identify main elements of the Education 4.0 frameworks available;
- (II) To evaluate the applicability of these elements for supporting Education 5.0 in the context of Technological Higher Education Institutions in Brazil;
- (III) To propose and validate a tailored set of elements for Education 5.0 that integrates the prioritized Education 4.0 elements, specifically designed for the unique challenges and opportunities in Technological Higher Education Institutions in Brazil.

1.4. Research justification

Education is a pillar of human development and societal progress, a status affirmed by its recognition as a fundamental human right (UNESCO, 2021). Historically, the effective dissemination of knowledge has been a hallmark of advancement, yet the past decade has ushered in a profound redefinition of educational paradigms. Technologies such as IoT, and AI have catalyzed the rise of Education 5.0, integrating sensor-based systems, AI-driven data processing, and personalized learning ecosystems (Agarwal *et al.*, 2025; Ahmad *et al.*, 2023). This paradigm mirrors the human-centric, technology-driven principles of Industry 5.0, prioritizing adaptability, innovation, and lifelong learning (Rahim, 2021).

For THEIs worldwide - including universities, colleges, and technical institutions - this shift heralds a departure from traditional, teacher-centric models toward dynamic, technology-enhanced environments. Education 5.0 promises to cultivate essential 21st-century competencies—critical thinking, digital literacy, and problem-solving—preparing learners for an AI-driven, globalized workforce (Ahmad *et al.*, 2023; Alharbi, 2023; Singh *et al.*, 2023). However, its adoption is far from uniform. Developing countries face formidable challenges, including inadequate infrastructure, limited educator capacity, and unequal access to AI- and ICT-driven tools (Agarwal *et al.*, 2025; Rahim, 2021).

This study is justified by the pressing need to address these disparities and facilitate Education 5.0 adoption in developing countries. With the global education technology market expected to grow at a 17% compound annual rate from 2021 to 2025 (Ahmad *et al.*, 2023), and 72% of THEIs in developing nations lacking basic ICT infrastructure (WEF, 2023), the stakes are high. Educators, as agents of change, require sustainable technological empowerment to overcome these barriers (OECD,

2019). By investigating how technological proficiency in education can be enhanced - through improved infrastructure, educator training, and equitable access - this research offers actionable insights and a tailored Education 5.0 framework, with a focus on emerging economies.

This SLR-base study is limited to published literature on the topic of education 4.0 framework, and education 5.0. To retain for analysis only the relevant literature, inclusion and exclusion criteria were defined. The following databases Scopus, IEEE, and Web of Science are used for the literature extraction. The keywords used were ("AI" OR "digital transformation") AND ("Education 4.0 Framework" OR "Education 5.0") in the search bar between 2020 and 2025. Only articles and conference papers published in English and Portuguese were selected in the databases.

An initial keyword search using as string the terms "Education 4.0 Framework" OR "Education 5.0" yielded 488 articles. However, their scope varied significantly, with many lacking a technological focus or addressing Education 5.0 only superficially. In some cases, Education 5.0 was merely referenced or discussed briefly alongside Education 4.0. A more refined search using "Education 4.0 Framework" AND "Education 5.0" returned no relevant articles, highlighting a research gap that this study aims to address.

To enhance the depth of the analysis, the search term "digital transformation" AND ("Education 4.0 Framework" OR "Education 4.0") was employed to identify Education 4.0 frameworks developed within the past five years. This initial step was intended to examine the structure and core elements of these frameworks. Subsequently, a broader search was conducted using the keywords "digital transformation" AND ("Education 4.0 Framework" OR "Education 5.0") to identify the key elements necessary for assessing the applicability of these frameworks in supporting the transition toward Education 5.0 within Technological Higher Education Institutions (THEIs).

A systematic literature review (SLR) was conducted across multiple academic databases, followed by duplicate removal and a structured screening process to ensure relevance and full-text accessibility. After applying predefined inclusion and exclusion criteria, a final set of core studies was selected for comprehensive analysis, complemented by additional sources identified through reference tracking. Further methodological details are presented in Chapter 2.6.

1.5. Delimitation of the research

This research centers on the contextualization of Education 5.0 within higher technology education systems in developing countries, with a specific focus on Brazil, as a representative case. Education 5.0 represents the convergence of AI, ICT, and IoT with student-centered pedagogies, marking a significant departure from the frameworks of Education 4.0, which emphasized digitalization and automation but lacked the human-technology synergy central to the 5.0 paradigm (Rahim, 2021). This study situates itself at the intersection of technological innovation and educational transformation, exploring how THEIs can adapt to this new reality amid the challenges of globalization and Industry 5.0 demands.

The scope is geographically delimited to Brazil, a critical area due to its economic significance and persistent educational disparities (IBGE, 2024). Temporally, the research focuses on literature and development until 2025, with emphasis on papers published from 2020 onwards, capturing the most recent advancements in Education 5.0 and aligning with the rapid pace of technological change (Agarwal *et al.*, 2025; Ahmad *et al.*, 2023). Thematically, it concentrates on three key dimensions of technological proficiency in education: (1) infrastructure deficits, (2) educator capacity building, and (3) equitable access to AI- and ICT-driven learning ecosystems. (Agarwal *et al.*, 2025; Ahmad *et al.*, 2023; Alharbi, 2023; Ciolacu *et al.*, 2019; Supriya *et al.*, 2024). These elements are essential to understanding the barriers and opportunities for implementing Education 5.0 in resource-constrained settings

The study sharpens its focus on Technological Higher Education Institutions (THEIs). THEIs play a critical role in equipping skilled professionals for Industry 5.0 and driving innovation. While global perspectives - such as successful implementations in Saudi Arabia and Malaysia (Alharbi, 2023) - provide comparative insights, the research prioritizes regional dynamics within Brazil, an area underexplored in existing literature. Methodologically, it employs a deductive, analytical-qualitative approach, building on Education 4.0 frameworks to propose an adaptable Education 5.0 framework to be validated by experts in technological proficiency in education.

This research does not directly address themes such as social diversity, inclusion of marginalized populations, or issues surrounding vulnerability and social inequities. Although these topics are relevant to contemporary educational discourses and to the ethical dimensions of Education 5.0, focus of this study is the technology,

skills, and innovation dimensions associated with the evolution from Education 4.0 to Education 5.0. Moreover, while the literature reviewed acknowledges the importance of socioemotional competencies and holistic human development, including empathy and communication skills (BRASIL, 2017b), this study does not delve into detailed discussions or analyses of educational practices aimed at promoting equity or addressing the specific needs of vulnerable groups. The perspective adopted aligns more closely with the technological-pedagogical axis of educational transformation, rather than with the sociopolitical aspects of educational inclusion (Maria *et al.*, 2021).

In short, themes such as racial, gender, and economic equity, while recognized as critical in the broader educational landscape, are not part of the analytical framework of this research. These are considered areas for future inquiry, especially within the context of implementing Education 5.0 in diverse and unequal societies like Brazil. By delimiting the research's scope in this way, the research ensures a focused investigation into how Education 5.0 can be structured in developing countries. This contextualization not only highlights the relevance of the study but also positions it as a bridge between global educational trends and localized needs in Brazil.

2. THEORETICAL PLATFORM

This chapter lays the theoretical foundation for understanding the transition from Education 4.0 to Education 5.0 within the context of Digital Transformation (DT) and Artificial Intelligence (AI) in Technological Higher Education Institutions (THEIs) in Brazil. It is divided into four main parts: the first explores the role of DT and AI in reshaping educational systems; the second analyzes five key Education 4.0 frameworks and their elements; the third focuses on the principles of Education 5.0, characterized by a human-centered paradigm, integration of AI technologies, and a pronounced emphasis on competencies; and the fourth examines the current landscape of Education 4.0 and 5.0 in Brazil, identifying local challenges and contextual factors. By combining global insights with the Brazilian reality, the chapter offers a solid theoretical basis for investigating how Education 4.0 frameworks can support the effective adoption of Education 5.0 in Brazilian THEIs.

This chapter is structured around the following sections: Digital Transformation, AI, Education 5.0, Education 4.0 Frameworks, Technical and Technological Education in Brazil, and concludes with a Systematic Literature Review (SLR).

2.1. Digital Transformation

Steve Jobs' metaphor of computers as a "bicycle for our minds" underscores the transformative power of technology in enhancing human potential, fostering accessibility and empowerment, and highlighting the critical role of control and governance (Ciolacu *et al.*, 2024). Digital transformation (DT) refers to the comprehensive integration of digital technologies across all aspects of an organization, fundamentally reshaping its operations and value delivery to customers. It necessitates continuous adaptation to emerging technological trends to maintain competitiveness (Gagan, 2023).

As (Oliveira & de Souza, 2021) argue, DT in education is shaped by a holistic interplay of technological, human, organizational, and pedagogical factors. The relationship between education and technology is both longstanding and intricate, with digital tools playing a crucial role in enabling students to convert information into knowledge (Boltsi *et al.*, 2024). However, one of the major challenges in education is the lack of digital infrastructure and access to technology. Many schools and colleges

in developing countries still lack essential digital infrastructure and internet connectivity, limiting students' ability to access educational resources and engage in online learning. This digital divide exacerbates existing educational disparities, hindering the progress of students who would otherwise benefit from these technologies. Another significant challenge is resistance to change among teachers and education administrators.(Singh *et al.*, 2023) Although higher education institutions provide extensive digital resources, tools, and facilities, these are predominantly accessible via smart devices (Singh *et al.*, 2023).

(Rahim, 2021) highlights that the evolution of education is increasingly shaped by Information and Communication Technology (ICT) and Artificial Intelligence (AI). This transformation aligns the advancements of the fifth generation of education (Education 5.0) with the Industrial Revolution 5.0 (IR 5.0). The (OECD, 2019) emphasizes the necessity of exploring future educational methodologies that integrate AI and ICT trends to effectively meet learners' needs. As ICT and AI become more globally pervasive, the traditional role of educators may diminish, particularly for those with limited technological expertise. The authority of knowledge, once centralized in educators, is being redefined by AI- and ICT-driven platforms that enhance and professionalize teaching and learning environments(Rahim, 2021).

Recent literature underscores the significance of DT in education and the adoption of diverse digital technologies (Mukul & Büyüközkan, 2023). DT in education extends beyond merely integrating technology into classrooms; it necessitates rethinking pedagogical approaches, fostering adaptive learning environments, and leveraging data-driven insights to enhance teaching and learning outcomes. This transformation promotes personalized learning experiences, increases accessibility, and fosters student engagement through interactive and immersive educational technologies such as AI-driven tutoring systems, virtual and augmented reality, and cloud-based learning platforms. Consequently, DT is not only reshaping traditional educational models but also driving innovation in curriculum design, assessment methods, and institutional strategies, ensuring that education remains relevant and responsive to the demands of the digital age.(McCarthy *et al.*, 2023)

2.2. Education 5.0

Education is a fundamental human right, a catalyst for the growth of an individual, and one of the most effective means of eradicating poverty and advancing gender equality, health, peace, and stability (Supriya *et al.*, 2024). As Kolandan (2019) states, career choice is a crucial factor in determining an individual's role and trajectory in society. To remain competitive in business, academia, and governance, stakeholders must stay informed about these evolving dynamics and address emerging challenges and opportunities, particularly in the field of education. Furthermore, Kolandan (2019) emphasizes, that technology has reached unprecedented levels of development and has become an indispensable tool in contemporary life, significantly influencing education.

The literature presents various terminologies for technology-based education, including online education, mobile education, digital education, and smart education (Mukul & Büyüközkan, 2023). A comprehensive literature review necessitates defining Education 5.0, which represents the fifth generation of education. According to Rahim (2021), the concept of Education 5.0, introduced in 2020, proposes an advanced educational paradigm that combines Artificial Intelligence (AI) with human consciousness and ethical awareness, enabling a smart curriculum focused on personalized, meaningful, and future-oriented learning. This approach also incorporates enabling technologies and practices such as high-speed networks, data-driven decision-making, blockchain-based credentials, and cybersecurity, ensuring trusted, resilient, and intelligent educational ecosystems. Additionally, it emphasizes active methodologies, neuroscience-informed learning, biofeedback for well-being, and the development of socioemotional competencies, strengthening both academic performance and holistic human development. In essence, Education 5.0 serves as a response to developments in ICT, AI, and biotechnology to foster active, creative, and reflective learning, emphasizing socioemotional and cognitive skills (Felcher *et al.*, 2022).

Education has undergone substantial transformations throughout history, evolving in parallel with industrial revolutions. The current stage, Education 4.0, aligns with the Fourth Industrial Revolution, characterized by digitalization, AI, and personalized learning (Mukul & Büyüközkan, 2023). Meanwhile, according to Alam (2022), Education 5.0 represents the future of education, prioritizing individualized

learning experiences over mere technological advancements. The historical progression from Education 1.0 to Education 5.0 highlights key phases and their significance in shaping modern pedagogy.

Education 1.0 is distinguished by unidirectional communication between teachers and students, where educators serve as the primary source of knowledge. Instruction is delivered through direct information transmission, emphasizing student engagement (Puncreobutr, 2016). The key attributes of Education 1.0 include an authoritative structure, passive student participation, a teacher-centered approach, and the exclusion of in-class technology (Ciolacu *et al.*, 2019; Pooworawan, 2015). Learning is confined to classroom settings, relying heavily on textbooks and prioritizing rote memorization within rigid curriculum standards (SUPRIYA *et al.*, 2024).

Education 2.0 marks the transition to an educational model suited to the demands of industrial societies in the 21st century. This phase incorporates Web 2.0 technologies such as blogs and podcasts into the learning process. Despite these advancements, Education 2.0 remains primarily focused on teaching rather than fostering creativity and engagement (Puncreobutr, 2016 . Pooworawan (2015) identifies key characteristics of Education 2.0, including enhanced communication and collaboration, an examination-based assessment system, a strong emphasis on knowledge retention, and a limited student-centered approach. Digital resources such as educational videos, interactive whiteboards, and online simulations supplement traditional teaching, fostering collaborative learning environments that encourage student participation (Jonathan Bishop, 2022).

Education 3.0 signifies the broader integration of technology into education. This phase combines traditional classroom instruction with online learning platforms and Learning Management Systems (LMS) (Supriya *et al.*, 2024). Education 3.0 offers rich, multicultural learning opportunities, empowering students to take greater responsibility for their education and contribute to knowledge generation. The proliferation of internet networks and personal computing devices facilitates easy access to information (Mukul; Büyüközkan, 2023). According to OECD (2019), Education 3.0 emphasizes a student-centered approach, transforming instructors into facilitators, counselors, and guides. It promotes self-directed learning, fosters dialogue, and replaces the traditional classroom model with dynamic learning environments. Digital tools are extensively utilized for content delivery, progress assessment, and asynchronous feedback, enabling personalized and self-paced learning experiences (Ydyrysbayev *et al.*, 2022).

Education 4.0 introduces a paradigm shift that prioritizes the development of transferable skills and incorporates cutting-edge technologies such as advanced robotics, the Industrial Internet of Things (IIoT), and 3D printing to prepare students for the Fourth Industrial Revolution (Chituc, 2022a). This era is characterized by a strong emphasis on "lifelong learning" as a core mission of educational institutions. Education 4.0 fosters skills such as collaboration, leadership, entrepreneurship, creativity, effective communication, sensory intelligence, global citizenship, teamwork, and problem-solving. Beyond a conventional educational framework, Education 4.0 cultivates critical thinking, encourages innovative problem-solving, and promotes scientific and analytical reasoning (Ciolacu *et al.*, 2019). Mukul; Büyüközkan (2023) outline the defining features of Education 4.0, including co-creation, innovation-based systems, interactive and practical training, home-based and alternative learning environments, personalized instruction, creativity-focused learning plans, widespread technological accessibility, increased reliance on virtual reality, and a commitment to continuous innovation and development.

Education 5.0 emerged in 2020 as a response to rapid technological advancements, particularly in AI and ICT. This educational paradigm introduces a smart curriculum that integrates AI and ICT to drive innovation and educational reform. Rahim (2019) asserts, that Education 5.0 requires significant curriculum transformations, necessitating the support and commitment of educators for its successful implementation. The context of Education 5.0 emphasizes the development of the whole individual, so Education 5.0 goes beyond technical knowledge and cognitive skills to prioritize emotional intelligence, empathy, collaboration, resilience, and ethical behavior as essential elements of 21st-century learning (Felcher *et al.*, 2022; UNESCO, 2021) These soft skills are considered fundamental for students to navigate a complex and ever-changing world shaped by rapid technological advancement.

As highlighted by Rahim (2021) and Felcher *et al.*, (2022), Education 5.0 promotes a learner-centered, human-focused approach, where socioemotional competencies are integrated into the curriculum to foster personal growth, responsible citizenship, and meaningful social interactions. These competencies are integral to equipping students with the evolving global landscape. However, according to the OECD (2019), the precise educational needs of students between 2025 and 2050 remain uncertain due to continuous advancements in ICT, AI, and emerging industries.

Education 5.0 is a new curriculum reform that would need the buy-in of educators for possible smooth implementation (Rumbidzai Muzira & Maupa Bondai, 2020).

There are also some requirements for transformation of the fifth generation of education, that underscores the necessity of securing educator support to ensure seamless adoption. Education 5.0 is structured around five key pillars: Research, Teaching, Community Service, Innovation, and Industrialization advocate for an educational model that fosters lifelong learning, enabling individuals to continually develop their knowledge and skills throughout their careers (Singh *et al.*, 2023). Unlike traditional memorization-based education, Education 5.0 promotes experiential learning tailored to personalized educational needs.

Table 1 provides a comprehensive overview of the key characteristics, pedagogical strategies, and technological advancements that differentiate each stage of educational evolution, spanning from the conventional, teacher-centric framework of Education 1.0 to the human-focused, AI-supported model of Education 5.0.

Education Phase	Characteristics & Key Features	References
Education 1.0	- Pre-digital era with one-way communication between teacher and student. - Teacher-centered system; students are passive learners. - Heavy reliance on textbooks and rote memorization. - Minimal use of technology; learning confined to classrooms.	(Ciolacu <i>et al.</i> , 2019; Pooworawan, 2015; Puncreobutr, 2016; Supriya <i>et al.</i> , 2024)
Education 2.0	- Early adoption of digital tools like blogs, podcasts, and Web 2.0 technologies. - Education remains teacher-centered but with increased collaboration and communication. - Students engage in limited interactive activities, mostly consuming digital content. - Online resources supplement traditional teaching methods.	(Jonathan Bishop, 2022; Pooworawan, 2015; Puncreobutr, 2016)
Education 3.0	- Integration of digital learning platforms, Learning Management Systems (LMS), and mobile education. - Transition from teacher-centered to student-focused education. - Students take ownership of their learning, exploring and generating knowledge. - Educators act as facilitators, guiding learners in self-directed study. - Widespread access to information via the internet and mobile devices.	(Mukul & Büyüközkan, 2023; OECD, 2019; Supriya <i>et al.</i> , 2024)
Education 4.0	- Aligned with the Fourth Industrial Revolution (Industry 4.0). - Focus on digitalization, artificial intelligence, and personalized learning. - Development of critical 21st-century skills: creativity, leadership, problem-solving, and global citizenship. - Greater reliance on immersive technologies such as VR, AR, IoT, and AI-driven personalized learning. - Emphasis on lifelong learning, innovation, and co-creation.	(Chituc, 2022a; Ciolacu <i>et al.</i> , 2019; Souza & Debs, 2024)
Education 5.0	- A shift toward human-centered, AI-driven education with an emphasis on ethics and humanism. - Preparation for future learning through personalized education models. - Five pillars: Research, Teaching, Community Service, Innovation, and Industrialization. - Aims to develop holistic, lifelong learners adaptable to evolving technological landscapes.	(Carvalho, 2023; Rahim, 2019; Rumbidzai Muzira & Maupa Bondai, 2020; Verma & Singh, 2021)

Table 1. Evolution of Education: From Education 1.0 to Education 5.0

Source: Author.

A well-established framework is essential for the successful implementation of Education 5.0, ensuring coherence in curriculum design, seamless integration of technology, and alignment with future workforce demands. Such a framework facilitates adaptive learning methodologies, fosters collaboration between academia and industry, and enhances the overall effectiveness of education in preparing students for an AI-driven world.

2.3. Education 4.0 frameworks

Education 4.0 emerged in the context of the Fourth Industrial Revolution, bringing the need for education to align itself with trends like artificial intelligence, Big Data, robotics, and other advanced technologies. According to Felcher *et al.*, (2022), Education 4.0 responds to Industry 4.0 by promoting productive use of digital technologies and transforming the nature of work and required skills. The importance of Education 4.0 since 2011 lies in its focus on equipping students with technical, cognitive, social, and emotional skills that are essential for the 21st-century workforce (UNESCO, 2021), making it a vital shift from traditional memorization-based learning toward active, student-centered, and technology-enhanced education.

Here are five currently established Education 4.0 frameworks that were designed to establish guidelines for the future of education.

2.3.1. Digital Education Ecosystems – DEEs

The rapid digital transformation driven by Industry 4.0 has redefined the competencies required in the modern workforce, necessitating an equally transformative approach in education. Education 4.0 emerges as a pedagogical framework aimed at equipping learners with the skills and knowledge necessary for this evolving industrial landscape. Within this paradigm, Digital Education Ecosystems (DEEs) play a critical role in restructuring educational practices through advanced digital technologies, data-driven methodologies, and intelligent automation (Chituc, 2022a).

According to Chituc (2022b) the Digital Education Ecosystems are established around five categories of challenges: ICT infrastructure, interoperability, development of artificial intelligence algorithms to aid education, implementation, security, data protection and privacy. The solution approaches for these challenges are the development of adequate digital education ICT infrastructure and architecture; development of interoperability standards; development of methods, software tools and algorithms for AI aided education and 5G; policy, regulation and blueprints; and regulations and mechanisms for data protection. Figure 1 illustrates the technical challenges and corresponding solution approaches associated with implementing Education 4.0 and Digital Enhanced Environments (DEEs). It highlights key issues

such as ICT infrastructure, interoperability, AI integration, implementation, and data protection, along with targeted strategies to address each challenge.

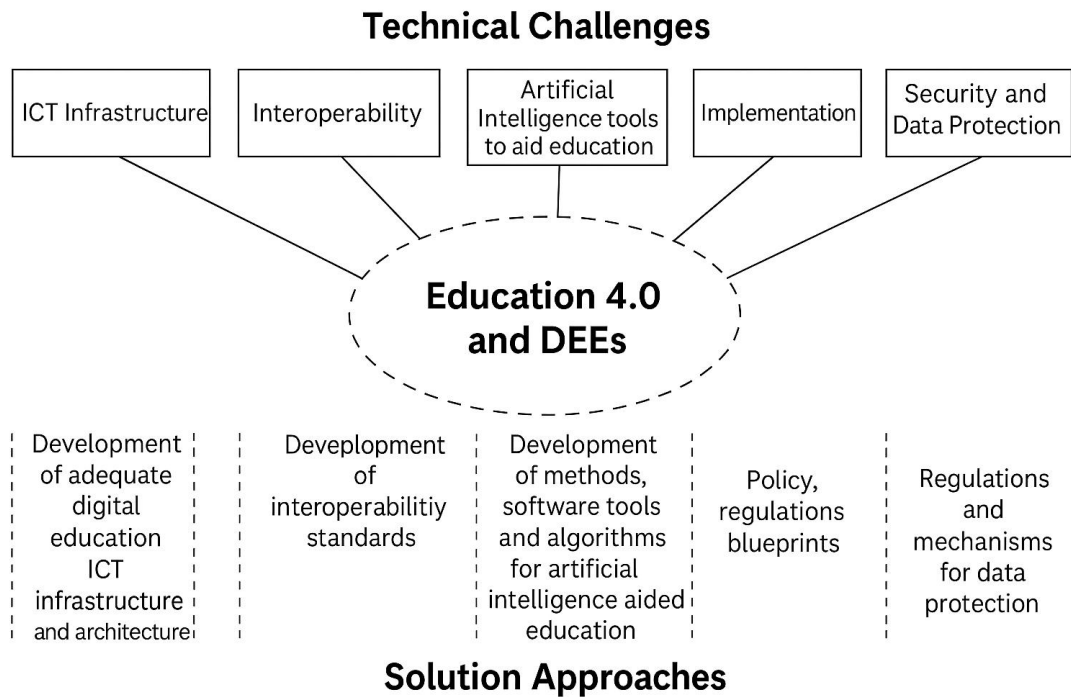


Figure 1: Education 4.0 and DEEs: Technical challenges and solution approaches
Source:(Chituc, 2022a).

2.3.2. Malaysian Higher Education 4.0 Framework

The Malaysian Higher Education 4.0 Framework offers a structured approach to the implementation, analysis, and continuous enhancement of educational systems. Serving as both conceptual and operational models, these frameworks guide policymakers, educators, and key stakeholders in navigating the complexities of higher education while ensuring coherence, efficiency, and adaptability.

Education 4.0 represents an evolutionary paradigm in education, designed to align learning processes with the digital transformation of Industry 4.0. This transformation is characterized by the integration of artificial intelligence (AI), the Internet of Things (IoT), cloud computing, and big data analytics into educational ecosystems. Within this context, the Malaysian Higher Education 4.0 Framework provides structured methodologies for curriculum development, pedagogical innovation, and the adoption of technology-driven learning models, ensuring that higher education institutions remain responsive to emerging technological advancements and global educational demands (Kolandan, 2019).

According to Kolandan (2019), the framework prioritizes four aspects, namely future ready curriculum, agile governance, talent planning and research and innovations. Under agile governance, the framework was focused on digital ethics and values, autonomous governance, ace delivery, sustainability and smart campus agendas. This includes neoteric values – driven academia and cognitive flexibility. Under research and innovation field, pioneer culture, research alliance and partnership, transitional research, commercialization of research and innovation. Figure 2 illustrates the Malaysian Higher Education 4.0 Framework, which outlines a strategic transformation of the national higher education system to align with Industry 4.0 demands. It emphasizes four key pillars—Future Ready Curriculum, Research and Innovation, Talent Planning, and Agile Governance—to produce adaptable, innovative, and future-ready graduates.

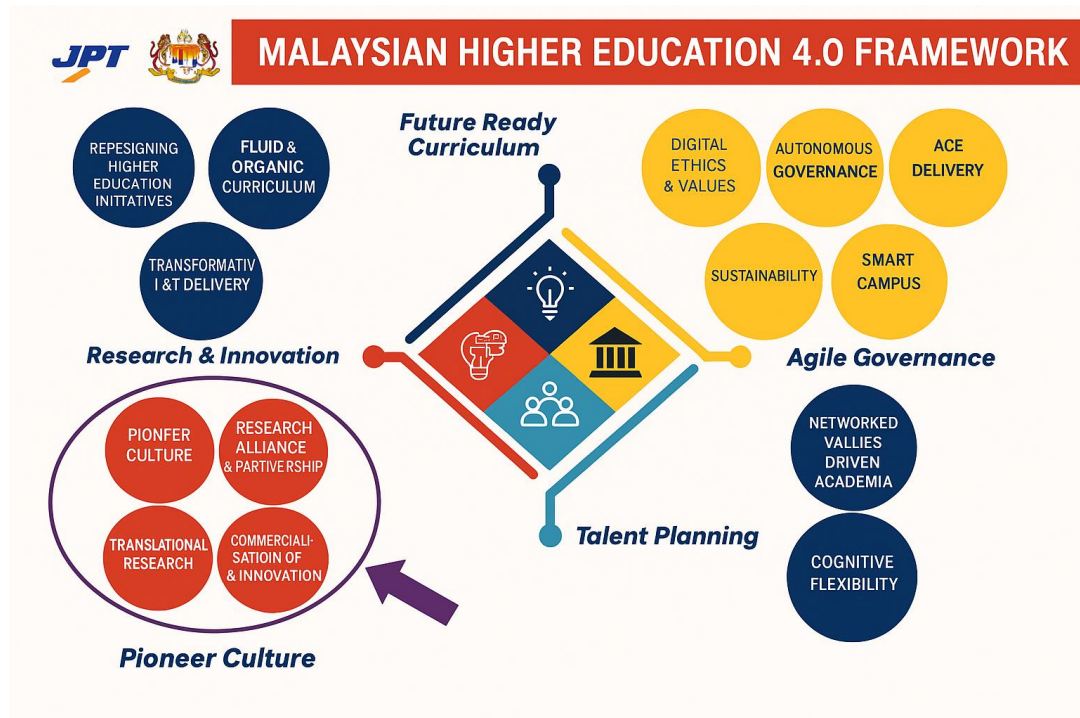


Figure 2: Malaysian Higher Education 4.0 Framework.
Source: adapt by the author (Kolandan, 2019).

2.3.3. STEM Learning

A framework in STEM (Science, Technology, Engineering, and Mathematics) education serves as a conceptual model that maps out the key characteristics, pedagogical approaches, and curriculum design strategies necessary for developing students' STEM literacy. This framework is designed to accommodate interdisciplinary

learning by integrating various disciplines into real-world problem-solving contexts. A STEM framework should be flexible, allowing different entry points and accommodating diverse pedagogical approaches (Falloon *et al.*, 2020).

Education 4.0 refers to the transformation of learning paradigms to align with the Fourth Industrial Revolution (4IR), characterized by automation, artificial intelligence, and digitalization. The STEM framework supports this evolution by promoting interdisciplinary learning, problem-solving, and design thinking—essential skills for navigating the complex challenges of the 4IR. The framework's emphasis on project-based and problem-based learning mirrors industry practices, making students more adaptable to emerging technologies and career demands (Falloon *et al.*, 2020). Figure 3 illustrates a framework for STEM education, emphasizing the integration of STEM disciplines—Science, Technology, Engineering, and Mathematics—through interdisciplinary, student-focused, and context-authentic learning processes. The model centers on developing STEM literacy by engaging learners in real-world problems and design thinking within dynamic educational environments shaped by curriculum, pedagogy, and work-related contexts.

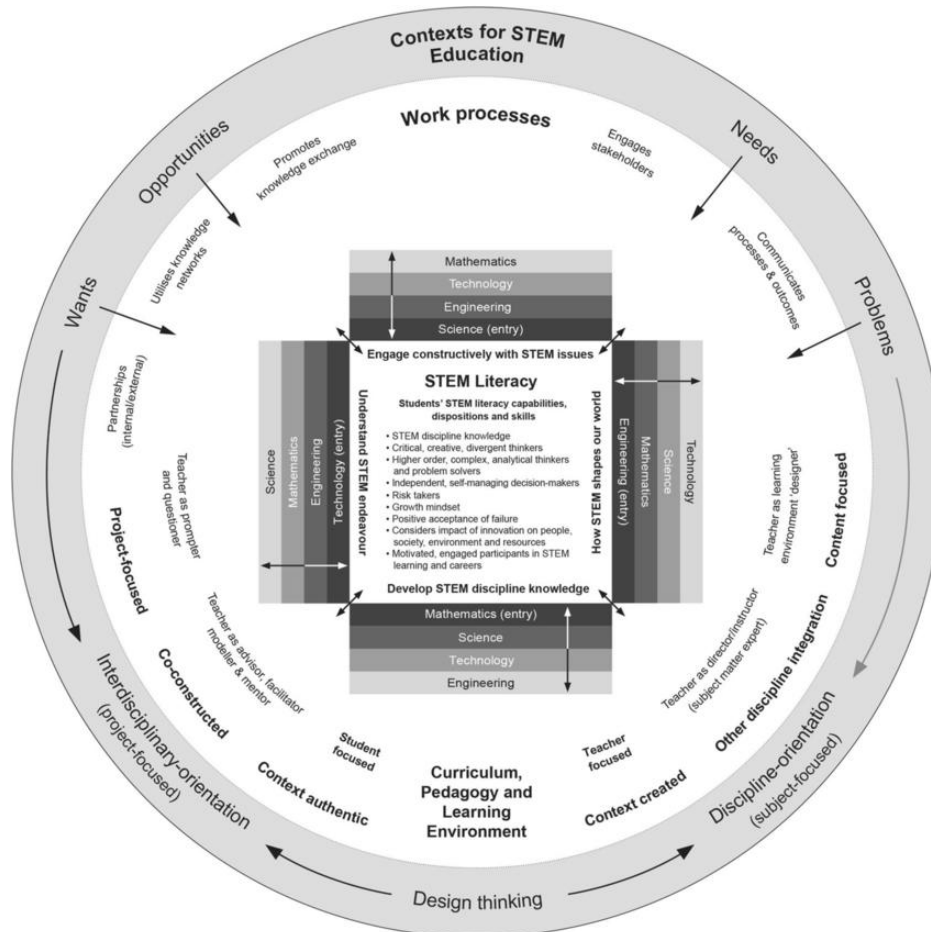


Figure 3: A STEM literacy development framework for STEM education.
Source: (Falloon *et al.*, 2020).

2.3.4. TADEO

The TADEO Method, an acronym for "Transformação Digital na Educação" (Digital Transformation in Education), is a pedagogical framework designed to integrate digital transformation principles into educational environments. This approach holistically aligns technological, human, organizational, and pedagogical drivers, fostering essential 21st-century competencies such as problem-solving, critical thinking, creativity, and digital literacy. The method is particularly significant within the Education 4.0 paradigm, which prioritizes the process of knowledge transmission over the mere delivery of content, emphasizing interactive, student-centered, and technology-enhanced learning experiences (Oliveira & de Souza, 2021)

Figure 4 illustrates the conceptual model of digital transformation in education, guided by international reports and supported by environmental and climate change education as pedagogical foundations. It identifies key drivers—technological, organizational, pedagogical, and competence-based—that shape the development of

both hard and soft student skills, with the TADEO method and supporting tools facilitating the transition toward Education 4.0.

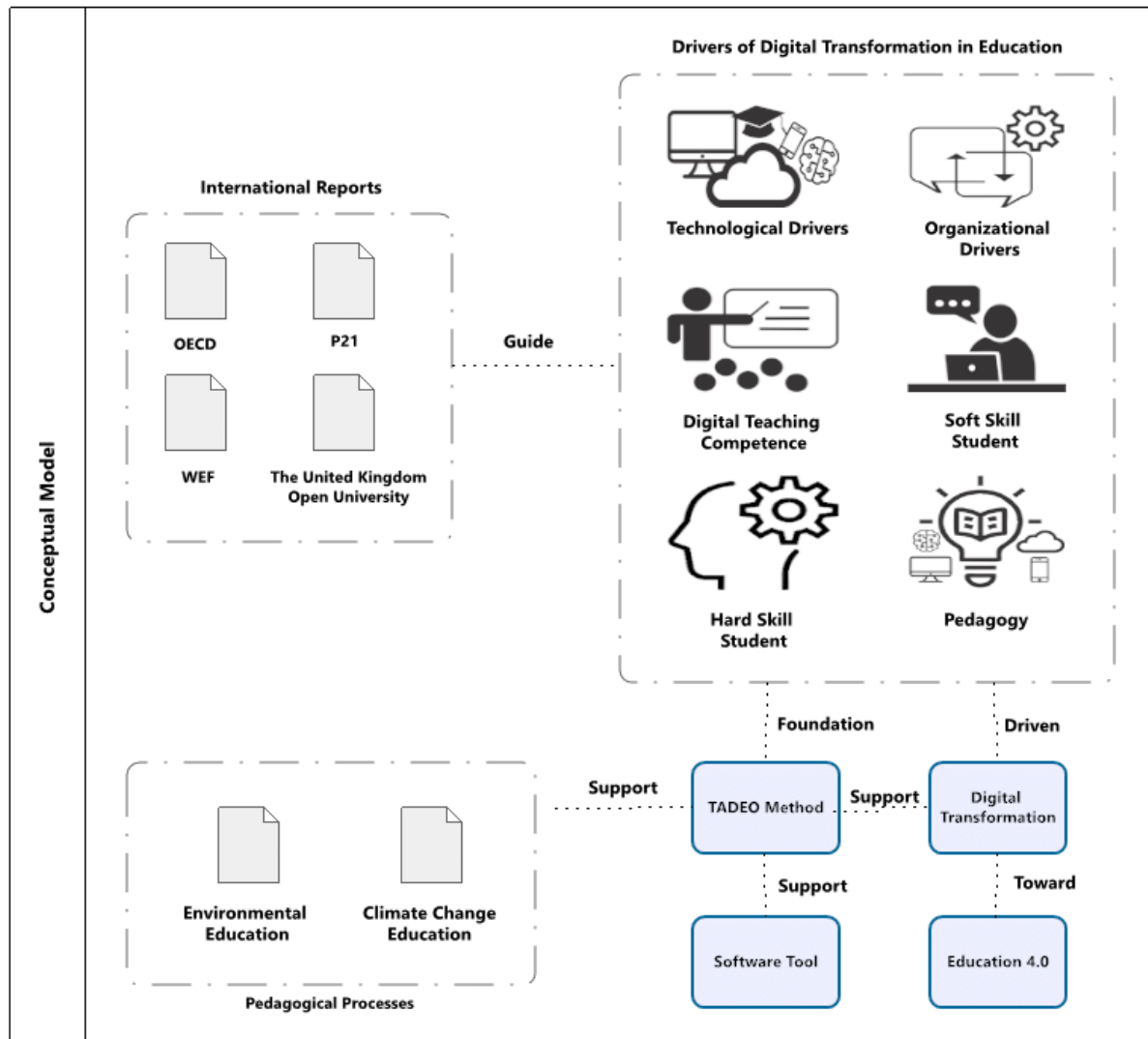


Figure 4: Conceptual Model of the TADEO Method

Source: (Oliveira & de Souza, 2021).

2.3.5. WEF Education 4.0 Framework

The Education 4.0 framework is designed to support the skill requirements of Industry 4.0, not only in digital technologies but also in the development of essential soft skills such as collaboration and lifelong learning (Venkatraman *et al.*, 2022). In the context of Education 4.0 and knowledge economy jobs, the emphasis shifts from the mere acquisition of concepts and theories to the ability to apply digital skills, knowledge, and technologies in an interoperable manner (Oliveira & de Souza, 2021).

According to Ahmad (2023), professional education within this framework must be adapted to incorporate new models of teaching and learning, with a particular focus

on interdisciplinary skills. Currently, there is no universally agreed-upon skill set that comprehensively addresses the evolving demands of the future labor market. However, one of the most widely referenced frameworks is that of the World Economic Forum (WEF). As stated by WEF (2023), the key skills are outlined in the World Economic Forum's Education 4.0 framework for 2023.

Figure 5 World Economic Forum's Education 4.0 framework illustrates the key elements of modern education reform by categorizing content and experiences that support skills adaptation and innovative pedagogy. The content focuses on building global citizenship, creativity, technological proficiency, and interpersonal skills, while the experiences emphasize inclusive, personalized, problem-based, and lifelong learning approaches tailored to individual learner needs.

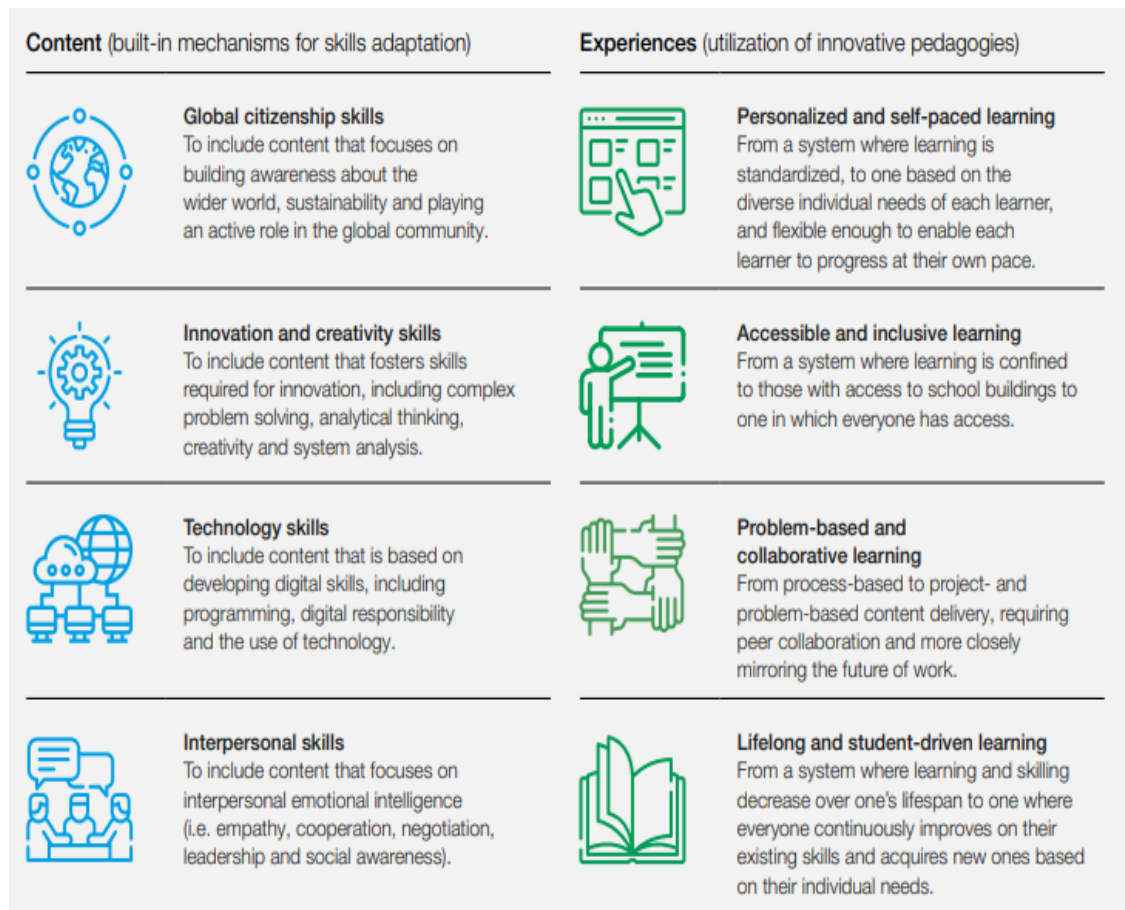


Figure 5: The World Economic Forum's Education 4.0 framework
Source: WEF (2023).

The World Economic Forum defines the teaching and learning of this set of abilities, skills, attitudes, and values as "Education 4.0" - a framework developed through extensive consultation with education experts from schools, non-profits,

education ministries, and the private sector, and refined through a series of previous publications (WEF, 2023).

2.4. Analyzing and comparing Education Frameworks

The education system incorporates the prevailing policies, structures, practices, and institutions that control education in a specific region or country. It comprises a wide range of elements like childhood education, primary and secondary education, higher education, vocational education and training, development in curriculum, methods of examination, and educational governance (Supriya *et al.*, 2024). In the context of education, DT involves rethinking the teaching and learning processes for an audience of digital natives, considering the practical aspects of the DT, through knowledge and technical skills, and being digital, through the incorporation of skill, mindset, and digital attitudes (Oliveira & de Souza, 2021).

According to Ciolacu (2024), Industry 5.0 aims to prioritize the development of people and societies that were overlooked in Industry 4.0 that unfolds across three interconnected levels. The first, the resilient level, is all about technologies that flex and adapt as the nimble backbone of a system that thrives amid uncertainty. Then there's the sustainable level, where the focus shifts to nurturing sustainability, ensuring the limits of our planet's ecosystems while still driving progress. Finally, the human-centric level brings people into the heart of it all, championing diversity, empowering individuals, and unlocking the potential of human talent. Together, these layers weave a vision of industry that's not just efficient, but deeply human and enduring. In this regard, Education 5.0 includes problem-based learning, scenario based learning and non-traditional labs approaches, increased interaction with AR/VR and AI technology and Biofeedback for well-being and health (Ciolacu *et al.*, 2024; Jonathan Bishop, 2022; Rumbidzai Muzira & Maupa Bondai, 2020; Ydyrysbayev *et al.*, 2022). Based on this, the five educational frameworks that are being used, are analyzed and compared, using the following three dimensions and key elements: technology, skills, and innovation.

2.4.1. Technology

The 11 key elements of the Technology dimension are presented below:

- **AI Literacy and Computational Thinking:** AI literacy should be woven into curricula, empowering students to understand, use and critically assess AI tools such as GenAI for learning, research and problem-solving (Agarwal *et al.*, 2025; Alharbi, 2023; Ciolacu *et al.*, 2024; Felcher *et al.*, 2022; Supriya *et al.*, 2024).
- **AI-Enhanced Ecosystems:** Implement GenAI tools in LMS to support formative assessment, content generation, and multilingual assistance (Agarwal *et al.*, 2025; Ahmad *et al.*, 2023; Ciolacu *et al.*, 2024; Supriya *et al.*, 2024)
- **Provide access to cutting-edge technologies—**such as PCB design software, VR/AR headsets, 3D printers, and high-definition cameras—for designing, simulating, and creating real-world systems. GenAI further enhances inclusivity through voice/text generation and multilingual capabilities (Alharbi, 2023; Ciolacu *et al.*, 2024; Souza & Debs, 2024)
- **Augmented and Virtual Reality (AR/VR):** Incorporation of AR/VR for immersive learning experiences, such as virtual labs and scenario-based simulations, enhancing interaction with complex systems (Ciolacu *et al.*, 2024; Felcher *et al.*, 2022; Souza & Debs, 2024; Supriya *et al.*, 2024)
- **Smart Infrastructure for Adaptive, Technology-Enhanced Learning:** The integration of cloud-based GenAI tools and IoT-enabled smart classrooms enables secure, real-time, and adaptive learning experiences by linking physical and digital environments under effective governance and institutional alignment. (Ciolacu *et al.*, 2024; Supriya *et al.*, 2024; Ahmad, 2023; Abdullah, 2023; Agarwal *et al.*, 2025).
- **Learning Analytics and AI Support:** AI-driven analytics and advisory systems to customize learning pathways with real-time performance updates of students (Agarwal *et al.*, 2025; Ahmad *et al.*, 2023; Alharbi, 2023; Ciolacu *et al.*, 2024; Maria *et al.*, 2021)
- **Blockchain for Credentials and Cybersecurity:** Secure and verifiable academic records and certifications (Ciolacu *et al.*, 2024; Supriya *et al.*, 2024; Ahmad, 2023; Abdullah, 2023).
- **High-Speed Networks (5G Networks) –** Discusses the importance of high-speed internet in education 5.0 (Ahmad *et al.*, 2023).

- Data-Driven Decision Making: GenAI supports analytics for early alerts, performance tracking, and resource optimization (Ahmad *et al.*, 2023; Felcher *et al.*, 2022; Maria *et al.*, 2021)
- Gamification: Implementing game-based system to drive motivation and applicability of engineering concepts in the real world (Ahmad *et al.*, 2023; Ciolacu *et al.*, 2024; Souza & Debs, 2024)
- Hybrid Learning: Blending online and in-person learning to provide flexibility and personalized education (Maria *et al.*, 2021; Rahim, 2021).

2.4.2. Skills

The 8 key elements of the Skills dimension are presented below:

- Analytical and Critical Thinking: Emphasis on developing skills to assess AI outputs, mitigate over-reliance, and maintain human judgment in decision-making processes (Ciolacu *et al.*, 2024; Maria *et al.*, 2021; Oliveira & De Souza, 2020; Souza & Debs, 2024; Supriya *et al.*, 2024).
- Collaboration with AI: Learning how to work alongside AI to enhance productivity (Supriya *et al.*, 2024; Ahmad, 2023).
- Ethical AI Use and Digital Literacy: Developing skills in prompt engineering, detecting AI bias, and ensuring responsible and ethical application of AI technologies, with attention to privacy, fairness, and ethical challenges .
- Complex Problem-Solving: Training in solving multifaceted, real-world problems using AI-augmented tools, aligning with human-centric and resilient frameworks for real world (Agarwal *et al.*, 2025; Ciolacu *et al.*, 2019; Maria *et al.*, 2021; Supriya *et al.*, 2024).
- Collaboration and Industry Engagement: Building communities of practice with industry to co-develop skills relevant to emerging job markets and technological trends (Alharbi, 2023; Ciolacu *et al.*, 2024; Souza & Medeiros Neta, 2021; Supriya *et al.*, 2024).
- Adaptability to VUCA/BANI Environments: Emerging future ready and robust skill sets for students to prepare them to withstand volatile, uncertain, complex, and ambiguous (VUCA/BANI) contexts (Ciolacu *et al.*, 2024; Felcher *et al.*, 2022; Supriya *et al.*, 2024).

- Lifewide and Self-Directed Learning: GenAI enables anytime, anywhere learning—across personal, professional, and academic settings—empowering citizen developers to solve real-world problems (Ciolacu *et al.*, 2024; Felcher *et al.*, 2022; Gartner, 2025; Maria *et al.*, 2021; Supriya *et al.*, 2024).
- Socioemotional Competencies: Developing communication, empathy, teamwork, and emotional management to enhance personal and professional growth (Felcher *et al.*, 2022; Rahim, 2021; Souza & Medeiros Neta, 2021).

2.4.3. Innovation

The 8 key elements of the Innovation dimension are presented below:

- Personalized and Adaptive Learning: Utilize AI to recommend courses based on individual strengths and weaknesses, promote flexible curricula, and support low-code/no-code and GenAI-integrated projects that enable experimentation and customized learning pathways (Alharbi, 2023; Rahim, 2019; Shailendra *et al.*, 2024; Souza & Debs, 2024)
- Problem-Based and Scenario-Based Learning: Shift toward competency-based, active learning models where students use AI and AR/VR to solve real-world problems. GenAI supports summarization, ideation, and hypothesis exploration, while citizen developers create practical AI tools to enhance learning experiences (Ciolacu *et al.*, 2024; Maria *et al.*, 2021; Rahim, 2021; Shailendra *et al.*, 2024; Souza & Medeiros Neta, 2021; Supriya *et al.*, 2024).
- Technology-Enhanced Learning Analytics: AI-driven analytics track student progress, providing insights to optimize teaching methods and learning outcomes (Ahmad *et al.*, 2023; Ciolacu *et al.*, 2024; Maria *et al.*, 2021; Rahim, 2021; Souza & Debs, 2024).
- Non-Traditional Labs: Shifting from conventional laboratories to virtual and AI-supported settings that replicate real-world standards, allowing students to brainstorm ideas with practical applications (Ciolacu *et al.*, 2024; Supriya *et al.*, 2024; Abdullah, 2023).
- Biofeedback for Well-being: AI-driven mental health monitoring and well-being support for students (Agarwal *et al.*, 2025; Alharbi, 2023; Ciolacu *et al.*, 2024; Felcher *et al.*, 2022; Supriya *et al.*, 2024).

- Reflective and Collaborative Teaching: Promote critical reflection on the role of AI in education while fostering collaboration among students, educators, and industry to drive innovation. Citizen developers serve as bridges between real-world needs and institutional technology (Agarwal *et al.*, 2025; Alharbi, 2023; Ciolacu *et al.*, 2024; Gartner, 2025; Maria *et al.*, 2021; Shailendra *et al.*, 2024; Souza & Medeiros Neta, 2021).
- Active Methodologies: Implement strategies like flipped classrooms and project-based learning to foster student protagonism and critical engagement (Maria *et al.*, 2021; Souza & Medeiros Neta, 2021) .
- Neuroscience: Applying insights from brain science to design strategies that enhance learning and emotional engagement (Felcher *et al.*, 2022; Maria *et al.*, 2021).

Figure 6 illustrates the foundational elements of the framework Education 5.0, emphasizing a synergistic integration of the pillars Technology, Skills, and Innovation. It highlights the role of emerging technologies such as AI, AR/VR, and blockchain, alongside critical skills like ethical AI usage, industry collaboration, and lifelong learning, all supported by adaptive, problem-based, and learner-centered teaching approaches aimed at preparing students for future-ready, human-centered education. The configuration of these dimensions and elements was developed by the author, grounded in the findings of an extensive bibliographic review (Alharbi, 2023; Ciolacu *et al.*, 2024; Felcher *et al.*, 2022; Maria *et al.*, 2021; Souza & Debs, 2024; Souza & Medeiros Neta, 2021; Supriya *et al.*, 2024).

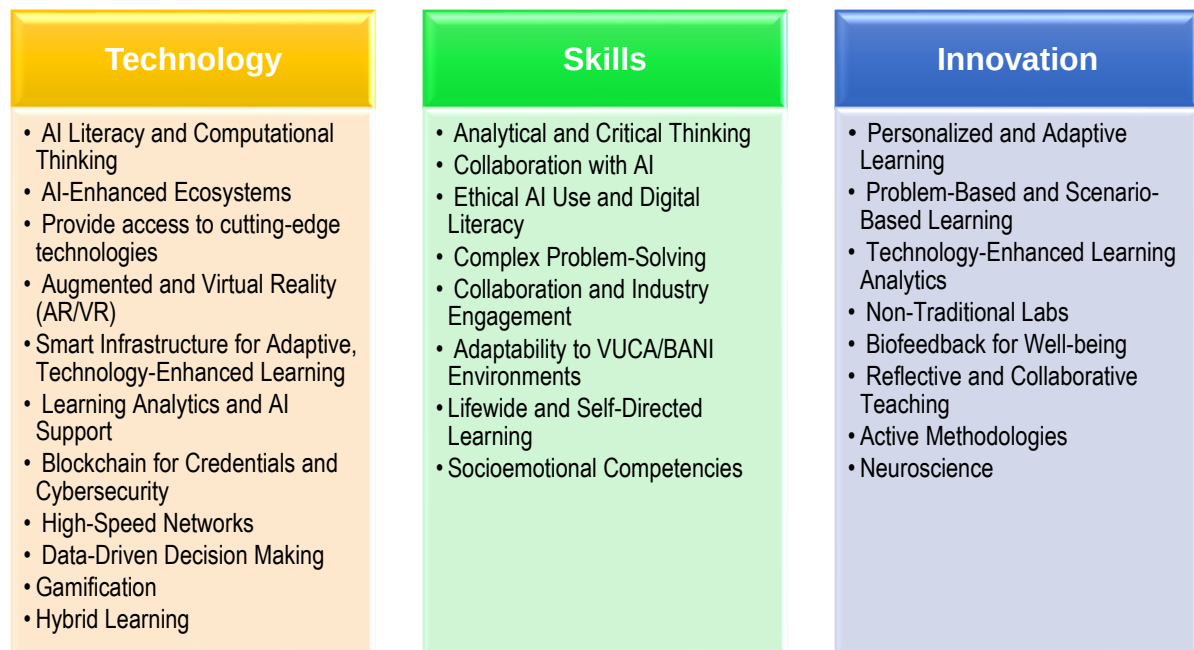


Figure 6: The dimensions and the key elements for Education 5.0.

Source: Author.

Table 2 displays the key elements identified within the five educational frameworks analyzed. It emphasizes three dimensions and 27 elements: Technology (11 elements), Skills (8 elements), and Innovation (8 elements). This analysis emphasizes the most critical elements within each dimension, offering a comprehensive understanding of their functions and interconnections within educational frameworks. Elements highlighted in blue signify their inclusion within the framework, whereas those without highlighting indicate their exclusion from the five educational frameworks considered.

Dimensio	Key Elements	DEES	MALAYSIA N	STEM	TADE O	WEF
Technology	AI Literacy and Computational Thinking					
	AI-Enhanced Ecosystems					
	Provide access to cutting-edge technologies					
	Augmented and Virtual Reality (AR/VR)					
	Smart Infrastructure for Adaptive, Technology-Enhanced Learning					
	Learning Analytics and AI Support					
	Blockchain for Credentials and Cybersecurity					
	High-Speed Networks					
	Data-Driven Decision-Making					
	Gamification					
	Hybrid Learning					
Skills	Analytical and Critical Thinking					
	Collaboration with AI					
	Ethical AI Use and Digital Literacy					
	Complex Problem-Solving					
	Collaboration and Industry Engagement					
	Adaptability to VUCA/BANI Environments					
	Lifewide and Self-Directed Learning					
	Socioemotional Competencies					
Innovation	Personalized and Adaptive Learning					
	Problem-Based and Scenario-Based Learning					
	Technology-Enhanced Learning Analytics					
	Non-Traditional Labs					
	Biofeedback for Well-being					
	Reflective and Collaborative Teaching					
	Active Methodologies					
	Neuroscience					

Table 2: Comparative analysis of the elements of Education 4.0 Frameworks against key elements of Education 5.0

Source: Author.

2.5. Technical-and technological education in Brazil

Parallel to the discussion on Education 5.0, the Federal Network of Professional, Scientific, and Technological Education, established by Law No. 11.892/2008, marks a historic milestone in Brazil's educational development. Tracing its origins to the 1909 Apprentice Artisans Schools, the network has significantly expanded in the 21st century, playing a central role in aligning technical education with contemporary social and economic demands (Souza & Medeiros Neta, 2021). In this context, computer technology assumes a strategic role, as emphasized by the Base Nacional Comum Curricular (BNCC), which frames digital culture and computational thinking as essential

general competencies to be developed across all levels of basic education. The BNCC highlights that digital technologies are not only instrumental in enhancing students' cognitive and creative potential but also indispensable for fostering autonomy, problem-solving, and innovation within a connected and rapidly evolving society (BNCC, 2025; BRASIL, 2017a). Therefore, integrating digital competencies, particularly through the expansion of computer and information technologies in education, is both a curricular imperative and a prerequisite for the effective realization of Education 5.0 in Brazil's professional and technological institutions.

The history of Vocational and Technological Education in Brazil is marked by key dates and legislation that served as turning points in discussions on management, organization, and workforce training in the country (Souza & Medeiros Neta, 2021)

The following years stand out:

Year	Law/Decree	Description and Impact on Technical Education
1909	Decreto nº 7.566	Established 19 Escolas de Aprendizes Artífices to provide primary-level professional and free education, aimed at equipping disadvantaged youth with technical and intellectual skills. This marked the foundation of formal technical education in Brazil.(BRASIL, 1909)
1937	Lei nº 378	Created Liceus Industriais, expanding the scope of technical education by introducing industrial-focused secondary education institutions.(Souza & Medeiros Neta, 2021)
1942	Decreto nº 4.127	Instituted Escolas Industriais e Técnicas and the Leis Orgânicas do Ensino, restructuring industrial education, reforming commercial and teacher training, and establishing the Serviço Nacional de Aprendizagem Industrial (SENAI). This decree broadened the framework for technical education and aligned it with industrial needs.(Souza & Medeiros Neta, 2021)
1959	Creation of Escolas Técnicas Federais	Established federal technical schools, consolidating technical education at the secondary level and enhancing their institutional structure.(Souza & Medeiros Neta, 2021)
1994	Lei nº 8.948	Gradually transformed Escolas Técnicas Federais and Agrotécnicas Federais into Centros Federais de Educação e Tecnologia (CEFETs), expanding their scope to include technological higher education alongside technical training.(Souza & Medeiros Neta, 2021)
2005	Decreto nº 5.840	Introduced the Programa Nacional de Integração da Educação Profissional com a Educação Básica na Modalidade de Educação de Jovens e Adultos (PROEJA), integrating professional education with basic education for youth and adults, addressing social inclusion.(BRASIL, 2006)
2008	Lei nº 11.892	Instituted the Rede Federal de Educação Profissional, Científica e Tecnológica and created the Institutos Federais de Educação, Ciência e Tecnologia. These institutes were defined as multi-level, multi-campus institutions offering professional, basic, and higher education, with a focus on integrating technical and technological knowledge. At least 50% of vacancies were reserved for integrated technical secondary education, and 20% for teacher training programs.(BRASIL, 2008)
2012	Lei nº 12.711	Mandated that 50% of vacancies in federal higher education and technical institutions be reserved for students from public high schools, with half of these for students from families earning up to 1.5 minimum wages per capita, enhancing access and social inclusion.(BRASIL, 2012)
2017	Lei nº 13.415	Reformed secondary education by introducing "itinerários formativos," which separated areas of knowledge and fragmented professional education by offering it as an optional track in the final stage of high school. This reform was criticized for undermining the integrated model of technical education promoted by the Institutos Federais.(BRASIL, 2017a)

Table 3. The history of Vocational and Technological Education in Brazil

Source: Author.

The implementation of Education 5.0 in Brazil faces numerous structural, pedagogical, and systemic challenges that hinder its effective integration, particularly in the context of higher technological education. As observed by (Felcher *et al.*, 2022)the persistence of Education 1.0 - characterized by a focus on traditional teaching and assessment practices - remains prevalent in many Brazilian educational institutions. This conservative educational paradigm significantly restricts the transformative potential of digital technologies (DT). The Covid-19 pandemic starkly

exposed these limitations: although remote education became necessary, in most cases it replicated conventional pedagogical methods in a virtual format, thereby failing to promote personalized and student-centered learning (Felcher *et al.*, 2022).

One of the primary obstacles is the insufficient technological infrastructure in educational institutions. Limited internet access, outdated equipment, and a lack of well-equipped laboratories compromise the integration of DT into classroom practices (Maria *et al.*, 2021). Equally critical is the gap in teacher training. The successful implementation of Education 5.0 requires educators who are not only digitally literate but also capable of fostering socioemotional development and embracing diversity through collaborative and creative approaches (Alves Guimarães *et al.*, 2023). However, most teachers receive inadequate preparation to meet these demands. As noted by Souza (2021), the absence of consistent public policies in teacher education results in many professionals acquiring skills "on the job," particularly in the field of professional and technological education.

Further compounding this issue is the structural fragmentation reinforced by the 2017 High School Reform (Law No. 13.415) (BRASIL, 2017a), which introduced formative itineraries. While intended to offer flexible learning paths, this reform has instead deepened educational duality and undermined the integration between general secondary and professional training (Souza & Medeiros Neta, 2021). Consequently, dropout rates, especially in Youth and Adult Education, remain alarmingly high (Alves Guimarães *et al.*, 2023; Felcher *et al.*, 2022; Maria *et al.*, 2021; Souza & Medeiros Neta, 2021).

In the context of professional education, the challenges are equally significant. The current teacher licensing system in Brazil does not adequately prepare educators for the specificities of professional and technological education. Many instructors hold only bachelor's degrees without pedagogical qualifications, which obstructs the adoption of interdisciplinary and integrated curricula - an essential component of omnilateral education (Souza & Medeiros Neta, 2021). Traditional pedagogical practices based on memorization and reproduction persist, reflecting not only resistance to change but also a lack of training aligned with the competencies required by Education 5.0 (Felcher *et al.*, 2022). Additionally, recent years have witnessed detrimental shifts in public policy, including significant budget cuts and the devaluation of scientific knowledge—exacerbated by denialist narratives during the pandemic.

These developments highlight the urgent need for a transformative educational model grounded in the principles of Education 5.0 (Felcher *et al.*, 2022).

It is important to delimit the scope of this research: the present study focuses exclusively on Brazilian Technological Higher Education Institutions that offer short-cycle, technology-oriented undergraduate programs. These programs, commonly referred to as “*cursos superiores de tecnologia*” in Brazilian Portuguese, typically span two to three years and are tailored to meet specific labor market demands. They are officially recognized by the Ministry of Education (MEC) and are offered across a variety of institutional types, including:

- Universities: Both public and private, these institutions offer a broad range of programs, including technology degrees, with an emphasis on teaching, research, and extension.
- University Centers: Multidisciplinary institutions similar to universities but without the legal obligation to engage in research.
- Colleges: Institutions that tend to specialize in narrower fields and have limited autonomy compared to universities.
- Federal Institutes (IFs): Public institutions dedicated to professional and technological education, offering both secondary-level technical training and higher education technology degrees.
- Federal Centers for Technological Education (CEFETs): Focused on the integration of technical and technological education, particularly in engineering and applied sciences.
- Technological Universities: Institutions whose core mission centers on advancing technological and professional education.

This study exclusively explores the dimensions of technology, skills, and innovation within the implementation of Education 5.0 in the context of technological education in Brazil.

2.6. Systematic Literature Review (SLR)

The research unfolds across two distinct phases. In the first phase, bibliographic research and a systematic literature review (SLR) are conducted in accordance with PRISMA 2020 guidelines (Page *et al.*, 2022a), ensuring methodological rigor, transparency, and reproducibility.

Bibliographic research and a systematic literature review (SLR) will be conducted in accordance with the PRISMA guidelines. Page(2022a) define bibliographic research as research “prepared from already published material, consisting mainly of books, magazines, publications in periodicals and scientific articles, newspapers, bulletins, monographs, dissertations, theses, cartographic material, and internet sources, with the aim of putting the researcher in direct contact with all the material already written on the subject of the research.” By synthesizing recent developments, debates, and insights, this study seeks to provide a comprehensive understanding of the emerging educational paradigm.

The systematic literature review (SLR) plays a vital role in extracting key insights from an ever-expanding body of published research, which is often overlapping or contradictory (Morandi & Camargo, 2015). The PRISMA 2020 statement offers a methodological framework for conducting systematic reviews. Originally developed in 2009, the PRISMA statement was designed to help researchers transparently report the rationale behind their reviews, the methods applied, and the findings obtained. The updated PRISMA 2020 statement replaces its predecessor, incorporating advancements in methods for identifying, selecting, appraising, and synthesizing studies (Page *et al.*, 2022b). Figure 7 presents the PRISMA 2020 flowchart, which illustrates the systematic process of identifying, screening, and including studies for a comprehensive literature review. It provides a transparent overview of the number of records retrieved, excluded, and ultimately included, ensuring methodological rigor and reproducibility.

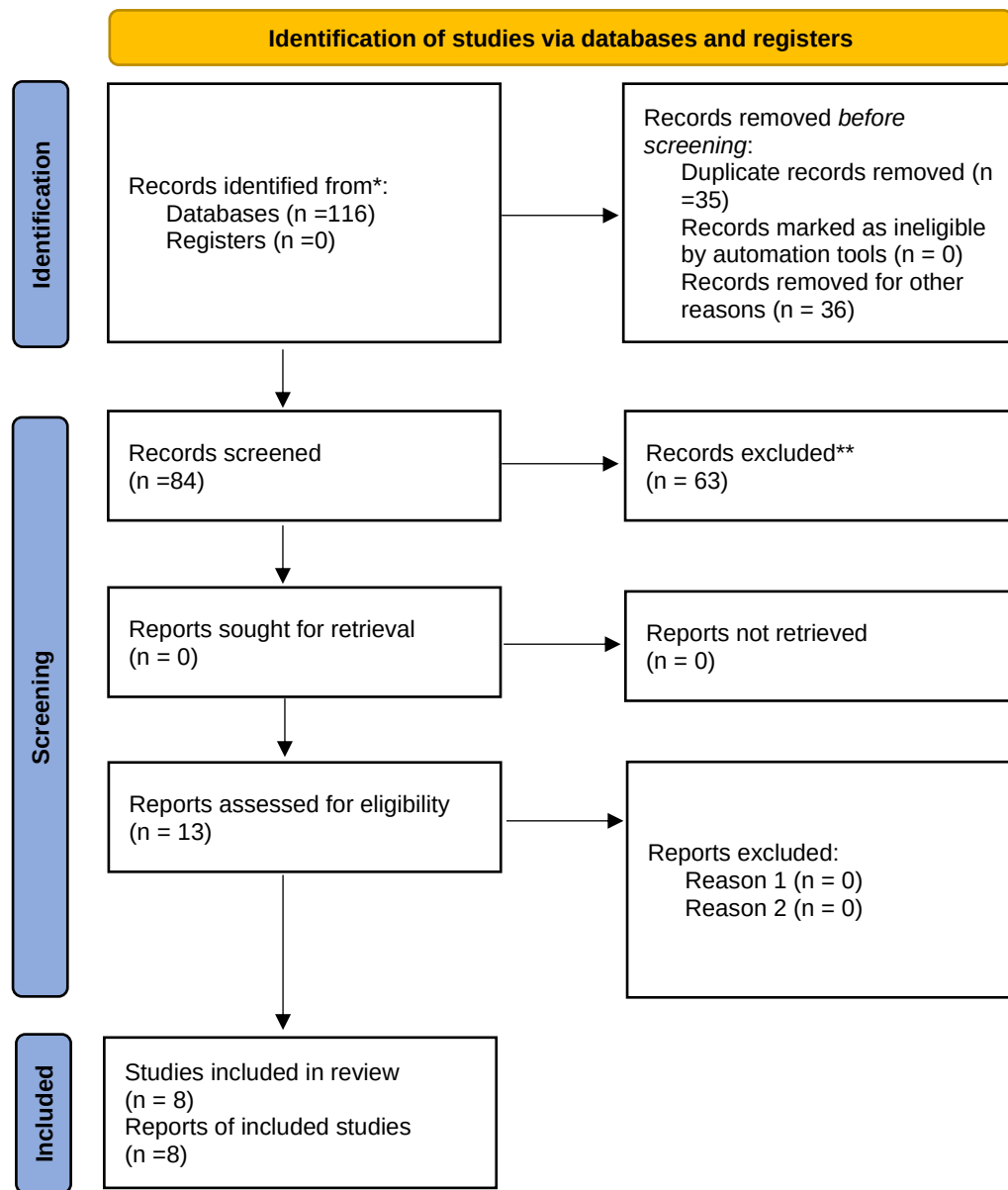


Figure 7: PRISMA 2020 flowchart for systematic reviews
Source:(Page *et al.*, 2022b).

The bibliographic research process commences with the selection of a topic and a preliminary survey to identify existing studies. This step is followed by the formulation of the research problem and an in-depth literature review utilizing both online and library resources. Relevant texts are then selected and categorized into primary, secondary, and tertiary sources for further analysis. Key ideas are systematically documented, analyzed, and interpreted, with findings subjected to critical evaluation. This phase concludes with a comprehensive interpretation, ensuring coherence and a meaningful contribution to academic knowledge, thereby laying a robust foundation for the final thesis or dissertation(Gil, 2007).The SLR completes Phase 1.

The SLR in this study focuses on published literature concerning Education 4.0 frameworks and Education 5.0. To ensure relevance, specific inclusion and exclusion criteria were established. Literature was sourced from the Scopus, IEEE, and Web of Science database, using the search string ("AI" OR "digital transformation") AND ("Education 4.0 Framework" OR "Education 5.0"). The publication timeframe was restricted from 2020 ongoing, and only articles and conference papers published in English or Portuguese were included. The scope of the research was limited to the year 2020 onward, as noted by RAHIM (2021), since this marks the introduction of the fifth generation of education (Education 5.0), which aims to integrate Artificial Intelligence (AI) with elements of consciousness. Three articles and one website were included in the research; these sources were found in the reference list of other articles.

For the SLR, the search string and methodology adhered to the inclusion and exclusion criteria, ensuring the selection of relevant and consistent academic literature (Liao *et al.*, 2017).

I/E	Criteria	Criteria explanation
Exclusion	From 2020 onwards	All the articles were above 2020
	Only articles and conference paper	31 non-article sources were excluded.
	Only English or Portuguese	One article was excluded, only articles in English were included; none were in Portuguese
	Duplicate articles	Next, 35 articles were duplicates found in more than one database.
	Articles without full-text access	Then 21 articles were excluded due to lack of access to the full text.
	Not specifically focused on Education 5.0	And finally, 15 articles were excluded for not focusing specifically on Education 5.0.
Inclusion	Articles and conference papers from references	Eight articles were included
	Websites from references	Three websites were included based on the reference of another article.

Table 4: Inclusion and exclusion criteria applied to SLR
Source: Author.

Exclusion criteria were applied to eliminate papers lacking full-text availability or those not specifically addressing Education 5.0. To uphold academic rigor, the scope was narrowed by employing a refined search with the terms ("AI" OR "digital transformation") AND ("Education 4.0 Framework" OR "Education 5.0") across three academic databases (Scopus, IEEE, and Web of Science), resulting in 116 articles. Only conference papers and peer-reviewed journal articles published between 2020 and 2025 in English or Portuguese were retained.

After screening, 84 articles were identified as relevant, with 49 duplicates removed. Then 21 articles were excluded due to unavailable full-text access, and 15 additional papers were excluded for not specifically addressing Education 5.0, leaving 13 articles. Eight additional sources (journal articles and conference papers) were included based on references from the selected literature, and three websites were incorporated for supplementary information, resulting in a final dataset of nine articles. This rigorous process ensured a curated, methodologically sound dataset, advancing the scholarly discourse presented in this thesis.

3. RESEARCH METHOD AND MATERIALS

This chapter presents the methodological framework used to identify and characterize the main elements of current Education 4.0 frameworks that could facilitate the adoption of Education 5.0 in Technological Higher Education Institutions (THEIs) in Brazil. The research follows a qualitative, exploratory-descriptive design, developed in two phases: first, a systematic literature review (SLR) to identify and analyze existing Education 4.0 frameworks; second, a mixed-methods validation phase involving questionnaires and semi-structured interviews with experts. The SLR follows the PRISMA 2020 guidelines (Page *et al.*, 2022b), and concentrates on technological skills and strategies in technological education, deliberately excluding themes like diversity, inclusion, and vulnerability, which fall outside the study's scope. To ensure contextual accuracy, the expert participants are drawn from a range of Brazilian THEIs.

This dissertation employs a qualitative, exploratory-descriptive approach to examine how Education 4.0 frameworks can support Education 5.0 in Technological Higher Education Institutions (THEIs) in developing countries, with a particular focus on Brazil. Following Creswell (2009), this method is chosen for its ability to explore complex and under-examined phenomena through in-depth analysis.

The research unfolds across two distinct phases. In the first phase, bibliographic research and a systematic literature review (SLR) are conducted in accordance with PRISMA 2020 guidelines (Page *et al.*, 2022a), ensuring methodological rigor, transparency, and reproducibility. This phase concentrates on identifying and analyzing Education 4.0 frameworks that could facilitate the transition to Education 5.0 in THEIs within developing countries. By synthesizing theoretical and empirical insights from relevant sources, the SLR seeks to map the structural elements of Education 4.0 frameworks, assess their applicability to Education 5.0, and inform the development of a tailored framework for Brazilian THEIs.

Building upon the findings of the systematic literature review (Phase 1), Phase 2 employs a mixed methods approach to validate and refine the proposed Education 5.0 framework. This phase utilizes two primary research instruments: a structured questionnaire and semi-structured interviews (Bowling, 1997; Creswell, 1994), designed to capture qualitative and contextual insights from an expert committee.

3.1. Research typology

To conduct a qualitative, exploratory-descriptive study, this research adopts methodologies that align with the principles of qualitative analysis. According to Santade (2014), “qualitative research is defined as a non-statistical study that precisely identifies and examines data that is challenging to quantify.” Essentially, it emphasizes subjective observation of the analyzed subject, illuminating it not through quantitative data or statistical samples, but rather through the analyses and interpretations of a researcher-observer (Creswell, 1994); further elaborates that qualitative research involves deeper exploration and interpretation of the research subject, though it does not facilitate broad generalizations of its findings.

Given the nature of this qualitative approach, “the researcher’s role is to act as an insightful and engaged intermediary, bridging the existing knowledge in the field with new insights derived from the study” (Lüdke & André, 2015). This perspective is perfectly aligned with the study’s aim to deepen understanding of an emerging educational paradigm.

Phase 2 employs two primary data collection instruments: a questionnaire and a semi-structured interview guide. These tools are designed to elicit qualitative insights into the elements of Education 4.0 frameworks and their potential to facilitate the implementation of Education 5.0 in Technological Higher Education Institutions (THEIs) in developing countries, with a specific focus in Brazil. A key objective of this phase is to evaluate the appropriateness of the questionnaire and its questions, ensuring they effectively capture the intended data. According to Bowling (1997), validity testing is essential to confirm that the study’s content aligns with its objectives and that the selected items are relevant for validation. This process also ensures the clarity and significance of the research topic.

As illustrated in Figure 8, Phase 2 comprises a three-step process designed to refine and validate the structured questionnaire and semi-structured interview script developed from Phase 1’s documentary research and Systematic Literature Review (SLR). In the first step, an Expert Committee composed of three to five PhD academics from Brazil’s *Stricto Sensu* Education programs, specialists in Education 4.0 and Education 5.0, will pre-test the instruments to assess clarity, relevance, and potential bias, with their feedback guiding the first round of revisions. In the second step, the revised questionnaire will be distributed to approximately 482 PhD researchers,

program, and coordinators from 21 graduate programs focused on digital transformation and technology in Education. These experts will evaluate the proposed competencies using a five-point Likert scale (1 = Not important, 2 = Slightly important, 3 = Important, 4 = Very important, 5 = Extremely important), suggest additional competencies, and provide recommendations for alignment with institutional standards. Finally, in the third step, the feedback will be synthesized and integrated with the findings from the SLR to draw conclusions and propose recommendations for the final set of dimensions and elements of Education 5.0, as outlined in Figure 8.

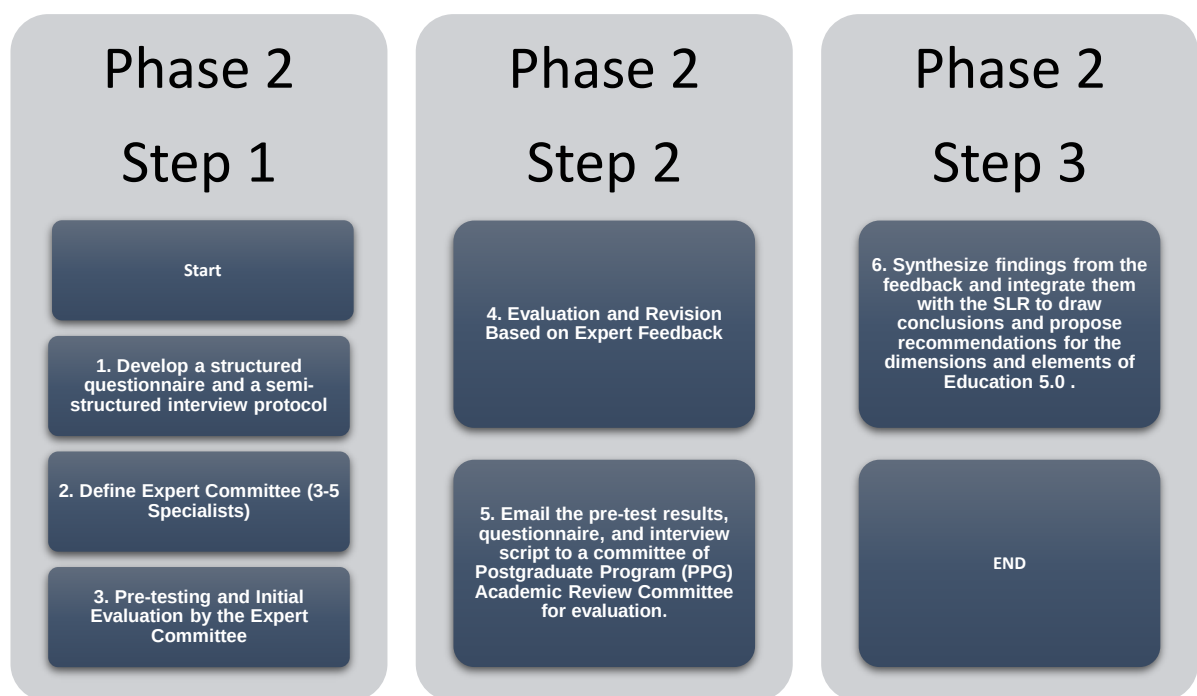


Figure 8: Phase 2 of the research
Source: Author

3.2. Universe, Sampling, and Sample

Guided by its objectives, this study addresses a theoretical problem by exploring potential solutions aimed at deepening the understanding of existing gaps within the field. It is anticipated that the findings from field research will contribute to advancing the state of the art and serve as a foundation for future investigations by academic researchers.

Phase 2 of this doctoral research consists of three key steps. This phase involves administering a survey to Technological Higher Education Institutions (THEIs)

to assess their level of technological proficiency in education. The proposed framework - comprising Dimensions and Key Elements - will be refined and validated through iterative feedback from PhD-level experts with specialized knowledge in technological proficiency in education within THEIs. This process is designed to ensure the framework's robustness and contextual relevance. Purposive sampling will be employed to select experts from *Stricto Sensu* programs who possess expertise in technological proficiency in education. with the objectives of this study (Bowling, 1997).

The research instruments for this phase include a questionnaire and a semi-structured interview script featuring both open-ended and multiple-choice questions. According to Manzini (2012), in defined populations, offering flexibility in the sequencing of questions and allowing interviewers to pose additional questions to gain deeper insights. Further notes that semi-structured interviews combine pre-established and open-ended questions, giving the interviewer greater control over the inquiry while encouraging spontaneous and reflective responses from participants (Minayo, 2015).

The first step, a pre-test, involves forming an Expert Committee of three to five PhD-level academics from *Stricto Sensu* programs in Education. These scholars will specialize in digital transformation and technology in Education, with research focusing on frameworks such as Education 4.0 and Education 5.0. Their expertise aligns closely with the study's objectives, ensuring robust feedback. The committee will review and evaluate the structured questionnaire and semi-structured interview script to be used in the second phase of the study.

In the second step, the feedback from the Expert Committee on clarity, relevance, comprehensiveness, and potential biases will be collected. The structured questionnaire and semi-structured interview script will be revised based on their suggestions. An email invitation, including the revised instruments and supporting materials to enhance understanding of the research topic, will be sent to selected researchers affiliated with graduate programs in Education. These PhD experts, including university administrators such as directors, deans, and academic coordinators, will focus on Education 4.0, Education 5.0, or digital transformation in THEIs.

To identify suitable candidates, the concentration areas and research lines of Brazil's 21 active graduate programs in Education will be analyzed, which can be found in Anex A. Assuming an average of eight experts per program, this yields a potential

pool of approximately 482 respondents. Programs with titles incorporating terms such as “digital,” “technological,” “technology,” or “professional” will be prioritized due to their alignment with the dissertation’s theme.

Professors and researchers affiliated with these programs who meet the eligibility criteria will be considered potential participants. Initially, all *Stricto Sensu* Education programs will be included, with special attention to those emphasizing digital or technological themes, indicating a strong alignment with the study’s focus.

After collecting written feedback or approval from PPG members to ensure alignment with institutional standards, the questionnaire and interview script will be analyzed and adjusted accordingly.

The third step involves synthesizing the specialists’ feedback and integrating it with the findings from the Systematic Literature Review (SLR). The results from the interviews will be combined with the SLR evidence to identify converging insights, validate the proposed dimensions and elements, and formulate conclusions and recommendations for a robust and context-appropriate dimensions and elements of Education 5.0.

3.3. Planned research instruments

The second phase involves the application of a questionnaire composed of both open-ended and multiple-choice questions, developed based on the findings from Phase 1. This instrument is designed to evaluate key elements associated with Education 4.0, while a complementary semi-structured interview guide is used to explore the applicability of these elements within the emerging framework of Education 5.0. The semi-structured format enables the collection of in-depth insights and allows for flexibility in participants’ responses (Creswell, 1994) .

According to Manzini (2012), a semi-structured interview is designed to study a phenomenon within a specific population, offering flexibility in the order of questions posed to interviewees. This approach allows interviewers to ask follow-up questions to gain deeper insights into the phenomenon. Minayo (2015) explains that a semi-structured interview combines pre-formulated and open-ended questions, enabling the interviewer to maintain control over topics of interest while fostering spontaneous responses and reflections from interviewees on key themes.

The first step of Phase 2 involves a pre-test with the Expert Committee to review the semi-structured interview guide, which can be found in APPENDIX A and comprises the following sections:

- **Introductory Text:** This section presents the researcher, delineates the research objectives, and clarifies key concepts, including digital transformation, Education 4.0, and Education 5.0, to ensure a shared understanding among participants.
- **Familiarity with Key Concepts:** This section evaluates the interviewee's knowledge of Education 4.0 and Education 5.0, providing context for their responses and ensuring alignment with the study's theoretical framework.
- **Core Dimensions:** Questions focus on three central dimensions—Technology (11 elements), Skills (8 elements), and Innovation Methodologies (8 elements). Experts will assess the relevance of these elements for Technological Higher Education Institutions (THEIs) using a five-point Likert-type scale (1 = Not important, 2 = Slightly important, 3 = Important, 4 = Very important, 5 = Extremely important) to rate the importance of each component (Likert, 1932).
- **Structural Adaptations:** This section solicits input on prioritizing elements of the Education 4.0 framework that can be adapted to support Education 5.0, addressing local needs while aligning with global trends. Experts will use a five-point Likert-type scale (1 = Not important, 2 = Slightly important, 3 = Important, 4 = Very important, 5 = Extremely important) to evaluate the importance of each component (Likert, 1932).

3.4. Research linkage matrix

The research linkage matrix (presented as Chart 1) aligns the study's general and specific objectives with theoretical frameworks, data collection instruments, and analysis techniques.

General Objective	Specific Objectives	Theoretical Framework	Data Collection Instrument	Data Analysis Techniques
Identify and characterize the main elements of current Education 4.0 frameworks that could facilitate the adoption of Education 5.0 in Technological Higher Education Institutions in Brazil.	To identify the elements of the main Education 4.0 frameworks available.	Education 4.0 frameworks such as DEEs (Chituc, 2022), Malaysian Higher Education 4.0 (Kolandan, 2019), STEM Learning (Falloon <i>et al.</i> , 2020), TADEO (Oliveira & de Souza, 2021), and WEF Education 4.0 (WEF, 2023).	Phase 1: Systematic Literature Review (SLR) following PRISMA protocol. (Page <i>et al.</i> , 2022a).	Qualitative content analysis (Santade, 2014).
	To evaluate the applicability of these elements for supporting Education 5.0 in the context of Technological Higher Education Institutions in Brazil.	Education 5.0 principles (Rahim, 2021; Singh <i>et al.</i> , 2023; Carvalho, 2023) and challenges in developing countries (Agarwal, 2023).	Content Analysis: Thematic coding of literature to map the elements for Education 5.0 (Creswell, 1994).	Thematic analysis of expert perspectives. (Bowling, 1997)
	To propose and validate a tailored set of elements for Education 5.0 that integrates the prioritized Education 4.0 elements, specifically designed for the unique challenges and opportunities in Technological Higher Education Institutions in Brazil.	Transition from Education 4.0 to 5.0 (Chituc, 2022; Alharbi, 2023; Agarwal, 2023).	Structured Questionnaire: Likert-scale (1-5) responses from experts to evaluate the importance of Education 4.0 elements for Education 5.0 (Likert, 1932).	A Likert-type scale (1932) will be employed, allowing experts to rate each competency on a five-point scale

Chart 1: Research anchorage table

Source: Author.

4. PRESENTATION, ANALYSIS, AND DISCUSSION OF RESULTS

This chapter presents the results obtained in research field applied, which involved the validation and refinement of the proposed main elements of Education 4.0 that promote the transition to Education 5.0 are grouped into three dimensions: technology, skills, and innovation. In the Technology dimension, elements such as AI literacy, smart and hybrid learning ecosystems, AR/VR, learning analytics, and data-driven decision-making. In Skills dimension emphasized analytical thinking, ethical and collaborative AI use, adaptability, lifewide learning, and socio-emotional competencies were included. In innovation, was highlighted personalized and problem-based learning, non-traditional virtual labs, biofeedback for well-being, reflective teaching, and active, neuroscience-informed methodologies. Together, these elements enable a human-centered, AI-supported, and sustainable Education 5.0 through expert evaluation. The objective of this stage was to ensure the methodological consistency, relevance, and applicability of the research within higher technological education institutions in Brazil. The data collected during this second phase were analyzed to identify key insights, challenges, and opportunities that emerged from the responses of the experts. In this phase, the experts contributed by analyzing each dimension and element, suggesting new elements, and refining the existing ones. The results are discussed in light of the theoretical foundations of Education 4.0 and Education 5.0, emphasizing how human-centered, technological, and sustainable dimensions converge to support the transition toward Education 5.0.

4.1. Instrument Development, pre-testing and validation of the questionnaire

The research process began with the careful development of a structured questionnaire designed to align directly with the central objective of the study, namely, to propose elements for Education 5.0 based on the evolution of elements found in Education 4.0 frameworks. In this phase, theoretical concepts were translated into clear, objective, and measurable questions capable of capturing expert perceptions regarding technology, skills, and innovation within the context of Brazilian Technological Higher Education Institutions.

To ensure methodological rigor and content validity, a panel composed of three PhD professors and researchers, active in the fields of professional and technological

education, postgraduate programs, digital transformation, and higher education, was invited to evaluate the initial version of the instrument. The expert committee was composed of three specialists whose academic and professional trajectories strongly align with the objectives of this research, particularly regarding Higher Education Institutions offering technology-oriented programs. The first specialist brings more than three decades of experience in higher and postgraduate education, with consolidated expertise in strategic planning, organizational transformation, knowledge management, complexity management, creativity, and innovation. Her background includes advanced international certifications in knowledge management and technology transfer, leadership positions in national research and administrative institutions, participation in international projects, and consultancy work in global development initiatives, demonstrating a solid strategic and technological perspective.

The second specialist combines extensive academic training in informatics, intelligent systems, software engineering, and knowledge management with over a decade of teaching experience in technical and higher education programs focused on technology. His research trajectory encompasses the development of intelligent systems, automated inspection tools, and participation in initiatives aimed at strengthening scientific and technological competencies, reinforcing his relevance to the validation of the elements proposed in this study.

The third specialist is an experienced executive in digital postgraduate education, with significant expertise in innovation, digital product development, and educational technologies, supported by advanced academic qualifications in administration and specialized training in entrepreneurship and innovation. With more than twenty years of experience in higher education and professional practice in strategic consulting, combined with her work as a mentor and communicator on the future of education and technological transformations, she contributes a broad and forward-looking perspective. Collectively, these experts' profiles reinforce the methodological rigor of the validation process, as all possess substantial experience in higher education, technology-related programs, and innovation-driven academic environments, fully aligned with the theoretical and practical foundations of the dimension and elements of Education 5.0.

Their task was to assess the clarity, relevance, and coherence of each question in relation to the core ideas of Education 5.0. Their feedback was crucial for refining the wording, reorganizing certain items, and adjusting the overall structure to achieve

greater internal consistency and conceptual alignment. This analysis covered the three dimensions and 27 elements, including 11 related to Technology, 8 to Skills, and 8 to Innovation.

Before implementation, a pre-test was conducted to assess the quality and reliability of the instrument. This stage allowed for minor adjustments that improved precision and ensured that the questions accurately reflected the objectives of the study and theoretical foundation. It also confirmed that participants could easily interpret each item and that the response scales were appropriate for evaluating levels of importance and relevance.

The panel of experts contributed significant insights that led to substantial refinements in the final version of the dimensions and elements of Education 5.0. Their feedback emphasized the need for a more comprehensive and future-oriented approach, particularly within the Technology dimension. They suggested incorporating smart and adaptive infrastructures that integrate IoT, cloud-based AI systems, and effective governance mechanisms to ensure alignment between digital and physical learning environments. The experts also highlighted the importance of access to emerging technologies – such as VR/AR, 3D printing, and generative AI – as well as the inclusion of sustainability principles within technological education. As a result, two new elements were added: Sustainability and SDG Literacy through Green and Digital Technologies and Responsible and Sustainable Tech Training, linking technological innovation to environmental and social responsibility.

Within the Skills dimension, the experts recommended deepening the human-technical integration of competencies, arguing that Education 5.0 should prioritize synergy rather than separation between these domains. This perspective gave rise to new elements such as Integration of Human and Technical Skills, Cognitive and Socioemotional Skills for 21st-Century Professionals, and Digital Citizenship and Expanded Digital Ethics were explicitly included to broaden the scope of this dimension. The experts also proposed broadening the ethical dimension to include Digital Citizenship and Expanded Digital Ethics, reflecting the complexity of responsible AI use and digital engagement. Additionally, they underscored the importance of adaptability to VUCA/BANI/RUPT environments and the development of lifelong and meta-learning capacities as central features of future-ready education.

Finally, in the Innovation dimension, the experts emphasized the need to strengthen the connection between education, industry, and society. They proposed

new elements such as Maker and Living Labs, Open Innovation and Productive Sector Collaboration, and Generative AI for Co-creation and Applied Research to encourage experimentation, interdisciplinary collaboration, and real-world application. Moreover, they recommended framing innovation not only as a technological endeavor but also as a social and sustainable process, culminating in the inclusion of Inclusion, Sustainability, and Societal Impact as a key element. Collectively, these expert contributions positioned the dimensions and elements as a forward-looking, human-centered model that integrates technology, skills, and innovation to support transformative learning ecosystems.

As a result, the final version of the instrument was validated and ready for expert application. Importantly, this stage also refined the proposed the Education 5.0 model. While the initial version included three dimensions and 27 elements, the analytical process and expert feedback expanded and enriched its structure to three dimensions and 35 elements. The qualitative data ensured that the resulting framework was both comprehensive and deeply grounded in expert insight, strengthening the methodological foundation of the research and enhancing its contribution to the understanding of a set of elements of Education 5.0. The modifications suggested by the three specialists are presented in the following sections, organized according to each analytical dimension considered.

4.1.1. Technology Dimension

In the first version of the dimensions and elements, which was developed from the foundations of Education 4.0 frameworks, the Technology dimension focused mainly on digital infrastructure and access to technological tools. Elements such as Artificial Intelligence (AI) literacy, Virtual and Augmented Reality (VR/AR), the Internet of Things (IoT), and Blockchain for academic credentials were identified as essential enablers of educational transformation. However, this early version presented technology primarily from a technical and instrumental perspective, emphasizing the availability of tools rather than their capacity to enhance pedagogical practices, institutional development, and social impact.

During the validation phase, the experts encouraged a broader and more human-centered view of technology. They emphasized the need for this dimension to represent technology not merely as a set of devices or systems, but as an engine for

learning innovation, institutional transformation, and the redesign of programs, courses, teaching practices, and student engagement. This perspective reinforces that technology should also serve as a catalyst for institutional transformation, contributing to the redesign of courses, the evolution of teaching practices, and the development of students' learning experiences. Their feedback highlighted the importance of integrating smart and adaptive infrastructures capable of connecting IoT, AI, and real-time analytics into coordinated environments. In addition, they reinforced the need for data-driven systems that support personalization, inclusion, transparency, and effective decision-making. Ethical, responsible, and sustainable technological use was also considered essential to ensure alignment with human development and the Sustainable Development Goals (SDGs).

As a result of these contributions, the Technology dimension expanded from 11 to 13 key elements, reflecting a more strategic, integrated, and socially oriented perspective. Beyond recognizing AI, IoT, AR/VR, and Blockchain as interconnected resources, the revised version incorporated new elements such as Sustainability and SDG Literacy through Green and Digital Technologies and Responsible and Sustainable Tech Training. These additions signal a clear shift toward a technology ecosystem that supports equity, environmental responsibility, long-term institutional growth, and the transformative aspirations of Education 5.0.

4.1.2. Skills Dimension

In the first version of the dimensions and elements, which was grounded in the principles of Education 4.0 frameworks, the Skills dimension emphasized cognitive and digital competencies considered essential for navigating increasingly technology-rich learning environments. Initial elements included analytical and critical thinking, digital literacy, collaboration with AI, adaptability to VUCA/BANI contexts, and socioemotional abilities. However, the early version approached these skills as separate domains rather than as interconnected capabilities supporting holistic personal and professional development.

During the validation phase, experts recommended reframing the Skills dimension to reflect the human-technical integration that characterizes Education 5.0. They emphasized that skills for the future must combine cognitive, socioemotional, ethical, and technological competencies, enabling learners to thrive in dynamic, AI-

mediated ecosystems. Their suggestions included expanding digital ethics into a more comprehensive notion of Digital Citizenship and Expanded Digital Ethics, strengthening the connection between human and technical competencies, and incorporating Lifewide, Self-Directed, and Meta-Learning as essential capacities for lifelong adaptability. Experts also stressed the importance of including competencies related to industry collaboration and complex problem-solving, reinforcing the relevance of real-world, interdisciplinary engagement.

In response to these recommendations, the Skills dimension evolved into a more extensive and integrated structure, moving from 8 to 10 key elements. New elements such as Integration of Human and Technical Skills and Cognitive and Socioemotional Skills for 21st-Century Professionals were added to reflect the need for synergy between personal development and technological fluency. The revised dimension positions skills not only as individual attributes but as interconnected capacities that enable agency, autonomy, professional relevance, and active participation in increasingly intelligent learning ecosystems.

4.1.3. Innovation Dimension

In the first version of the dimensions and elements, shaped largely by the pedagogical foundations of Education 4.0 frameworks, the Innovation dimension focused on teaching and learning methodologies. Elements such as personalized and adaptive learning, problem-based learning, active methodologies, reflective practices, non-traditional laboratories, and neuroscience were highlighted as innovative strategies to promote engagement and creativity. However, this early version conceptualized innovation primarily as a set of teaching practices, rather than as a broader institutional, social, and technological ecosystem.

During the validation process, experts recommended expanding the Innovation dimension to incorporate a more systemic and future-oriented perspective aligned with Education 5.0. They emphasized that innovation should reflect the dynamic interaction between education, industry, research, and society, encouraging experimentation, technology-enhanced collaboration, and interdisciplinary problem-solving. Recommendations included adding Maker and Living Labs to support prototyping and experiential learning, Open Innovation and Productive Sector Collaboration to promote institutional partnerships, and Generative AI for Co-creation and Applied Research as

an emerging force shaping new educational workflows. Experts also highlighted the need to include elements related to societal impact, equity, and sustainability.

Based on these contributions, the Innovation dimension expanded from 8 to 12 key elements, reflecting a shift from pedagogical method-centered innovation to ecosystem-centered innovation. The updated structure incorporates elements such as Inclusion, Sustainability, and Societal Impact and Biofeedback for Well-Being, reinforcing that educational innovation must integrate technological progress with human development, ethical responsibility, and social transformation. This broader and interconnected vision positions innovation as a strategic pillar for building adaptive, collaborative, and future-ready institutions capable of meeting the demands of Education 5.0.

4.1.4. Validated Version by expert committee

Chart 2 presents the consolidated results of Phase 2 step 1 of field research, showing the final composition of the Technology, Skills, and Innovation dimensions after expert validation. This stage enabled the systematic identification of retained, renamed, and newly incorporated elements, ensuring alignment with the principles of Education 5.0 and methodological rigor in the construction of the proposed framework. The following paragraph summarizes the quantitative distribution of elements across the three dimensions, as evidenced in Chart 2.

Dimension	Elements	Observation
Technology (13 elements)	AI Literacy and Computational Thinking	Retained
	AI-Enhanced Ecosystems	Retained
	Access to Cutting-Edge Technologies	Retained
	Augmented and Virtual Reality (AR/VR)	Retained
	Smart Infrastructure for Adaptive, Technology-Enhanced Learning	Renamed
	Learning Analytics and AI Support	Retained
	Blockchain for Credentials and Cybersecurity	Retained
	High-Speed Networks	Retained
	Data-Driven Decision Making	Retained
	Gamification	Retained
	Hybrid Learning	Retained
	Sustainability and SDG Literacy through Green and Digital Technologies	New
	Responsible and Sustainable Tech Training	New
Skills (10 elements)	Analytical and Critical Thinking	Retained
	Collaboration with AI	Retained
	Digital Citizenship and Expanded Digital Ethics	Renamed
	Complex Problem-Solving	Retained
	Collaboration and Industry Engagement	Retained
	Adaptability to VUCA/BANI/RUPT Worlds	Renamed
	Lifewide, Self-Directed, and Meta-Learning	Renamed
	Socioemotional Competencies	Retained
	Integration of Human and Technical Skills	New
	Cognitive and Socioemotional Skills for 21st-Century Professionals	New
Innovation (12 elements)	Personalized and Adaptive Learning	Retained
	Problem-Based and Scenario-Based Learning	Retained
	Technology-Enhanced Learning Analytics	Retained
	Non-Traditional Labs	Renamed
	Biofeedback for Well-being	Retained
	Reflective and Collaborative Teaching	Retained
	Active Methodologies	Retained
	Neuroscience	Retained
	Maker and Living Labs	New
	Open Innovation and Productive Sector Collaboration	New
	Generative AI for Co-creation and Applied Research	New
	Inclusion, Sustainability, and Societal Impact	New

Chart 2: Synoptic Chart – Dimensions and Elements of Education 5.0 validated in pre-test.

Source: Author.

The Technology dimension, after expert evaluation and refinement, was consolidated with a total of 13 elements, reflecting the maturity and centrality of technological infrastructures for Education 5.0; of these, 10 elements were retained from the initial proposal due to their continued relevance, 1 element was renamed to enhance conceptual clarity, and 2 new elements were incorporated to address emerging priorities such as sustainability and responsible technological training, as demonstrated in Chart 2.

The Skills dimension, which emphasizes human development aligned with complex and rapidly evolving professional contexts, resulted in 10 elements in total,

comprising 6 elements retained for their strong alignment with 21st-century competencies, 3 elements renamed to more accurately represent the integration of socioemotional, human-technical, and adaptability skills, and 1 newly added element, ensuring that the dimension reflects contemporary demands for lifewide, self-directed, and meta-learning, as shown in Chart 2.

The Innovation dimension, which broadens the scope from pedagogical methods to ecosystem-level innovation connecting education, industry, and society, was finalized with 12 elements, including 8 retained elements that remain essential to transformative learning practices, 1 renamed element to update its conceptual scope, and 3 new elements incorporated, capturing the increasing significance of maker environments, open innovation, and generative AI for co-creation and societal impact, as evidenced in Chart 2.

4.2. Results of the Academic Review Committee

In step two of the second phase, the version of the dimensions and elements validated by the experts' committee was submitted for a new round of validation and refinement based on the professors' and researchers' feedback. The questionnaire was distributed via email and completed through a Google Form by members of Postgraduate Programs (PPG) from universities and federal institutions offering master's and doctoral degrees in the areas of Professional and Technological Education. The purpose of this stage was to validate the proposed dimensions - Technology, Skills, and Innovation, and their corresponding elements in terms of clarity, relevance, and alignment with the principles of Education 5.0.

To ensure consistent evaluation, participants were asked to rate each element according to the following Likert scale: 1 (Not at all important), 2 (Slightly important), 3 (Important), 4 (Very important), 5 (Extremely important), and 9 (No conditions for an opinion). These categories were designed to capture both the perceived significance of each dimension/element and the degree of certainty in evaluations of the respondents. The members were also invited to assess the internal coherence of the framework, its applicability to diverse educational contexts in Higher Technological courses, and its potential contribution to advancing human-centered and technology-supported learning of Education 5.0. This systematic approach ensured a

comprehensive validation process, grounded in both quantitative and qualitative academic perspectives.

4.2.1. Members profiles

A total of 482 emails were sent to universities and institutions across Brazil, and 54 professor-researchers responded, resulting in a response rate of just over 12%. The committee was composed of highly qualified professor-researchers holding PhD and Post-Doctorate degrees, representing 17 Brazilian states (Figure 9), which ensured broad national representation.

The geographic and institutional diversity of the committee significantly strengthened the study. Because the participating members represented institutions from different regions of Brazil, the validation process incorporated varied educational realities, institutional contexts, and regional challenges related to Education 4.0 and Education 5.0. Their contributions enabled a rigorous analysis of the proposed dimensions and elements, resulting in a structure that reflects both academic rigor and practical relevance for the advancement of higher education in Brazil.

In total, the members represented 32 different institutions (CEETEPS, CEFET-MG, FATEC, FGV-SP, IF Goiano, IF Sudeste MG, IFAC, IFAL, IFB, IFBA, IFC, IFES, IFF, IFMA, IFMS, IFPR/IFMS, IFRJ, IFRS, IFS, IFSP, IFSul, IFTM, IFTO, INPI/IFRS, UFC, UFPR, UNEMAT, UNIARA, UNIJUÍ, UNINOVE, UNINTER, and USCS), of which 11% were private and 89% were public.

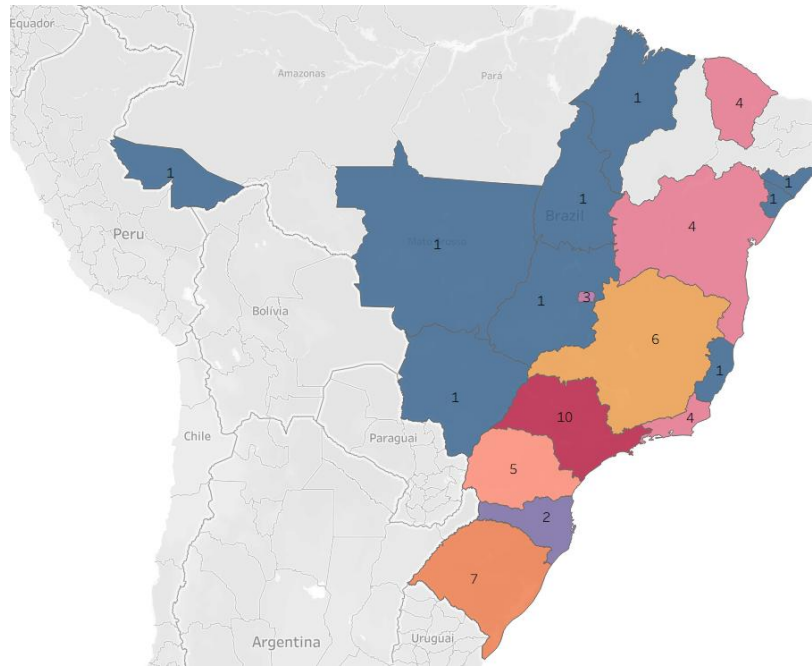


Figure 9: Total Number of Responses per State in Brazil
Source: Author.

Among the respondents, 69% held a doctorate and 31% held a post-doctorate, confirming the high academic profile of the group. All members are actively engaged in teaching and research in higher education, particularly within vocational, technological, and professional education programs. The distribution of years of experience in higher education among the PhD and post-doctoral members exposed in Figure 10, highlights the wide variation in professional trajectories within the committee. Their academic and professional trajectories include consolidated research experience, participation in graduate programs in universities, and between three and forty-five years of work in higher education (Figure 10). This combination of expertise and professional maturity significantly strengthened the quality and consistency of the evaluation process.

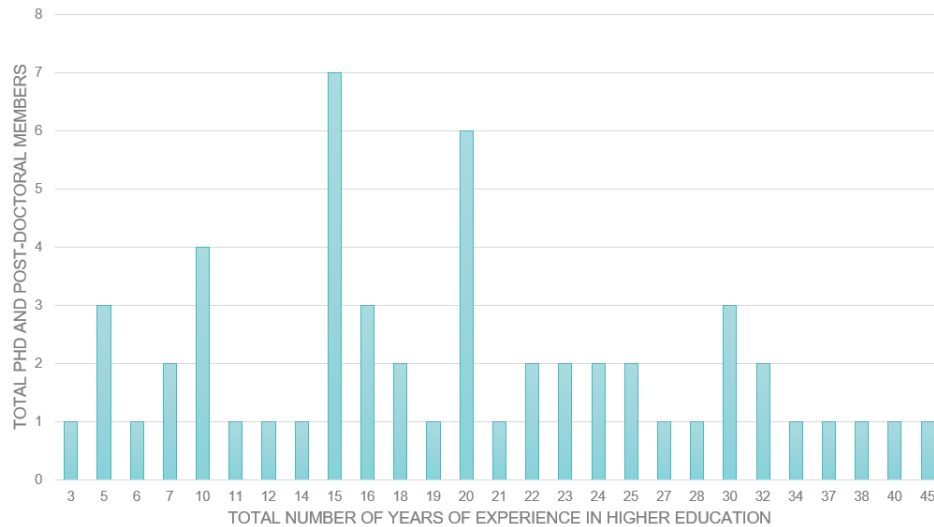


Figure 10: Total of academic backgrounds and extensive experience years within the group

Source: Author.

4.2.2. Technology Dimension

Each of the 13 elements within the Technology dimension was evaluated using the predefined scale from 1 (Not at all important) to 5 (Extremely important), with 9 indicating “No conditions for an opinion.” Participants were also allowed to provide qualitative comments for each item. Following a Delphi approach, consensus is typically identified when 70–80% of experts converge within the same high-relevance response range, representing a rigorous threshold for agreement. Additionally, less than 10% of ratings in the lowest categories (1 and 2) is commonly interpreted as indicative of minimal rejection of the item (Barrios et al., 2021).

The analysis of the results of the elements of the Technology dimension demonstrated a strong level of agreement among the 54 respondents. Overall, 39.7% (279 ratings) classified the technological elements as “Extremely important,” followed by 29.7% (209 ratings) as “Very important,” and 19.5% (137 ratings) as “Important.” Only 6.3% (39 ratings) selected “Slightly important,” 0.8% (6 ratings) chose “Not at all important,” and 6.1% (43 ratings) indicated “No conditions for an opinion.” These results show clear concentration of responses in the upper part of the scale.

In this study, 10 of the 13 technological elements reached a weighted average (WA) ≥ 4.0 , which corresponds to 80% of the maximum score, thus meeting the criterion for high relevance and indicating strong consensus among experts. The remaining three elements, which reached WA values slightly below 4.0, still met the

Delphi minimum threshold of 70% moderate consensus, showing that they were positively evaluated by a substantial proportion of the panel.

Elements such as Responsible and Sustainable Tech Training (WA = 4.5), AI Literacy and Computational Thinking (WA = 4.3), Smart Infrastructure for Adaptive, Technology-Enhanced Learning (WA = 4.3), High-Speed Networks (WA = 4.3), and AI-Enhanced Ecosystems (WA = 4.1) emerged as the highest-rated and most strongly validated components of the Technology dimension. Conversely, Learning Analytics and AI Support (WA = 3.9), Gamification (WA = 3.7), and Augmented and Virtual Reality (AR/VR) (WA = 3.5), although slightly below the 4.0 threshold, still demonstrated moderate expert agreement and low rejection rates, confirming that these elements remain relevant but were comparatively less prioritized by the panel.

Overall, the results indicate that all 13 elements are considered very important for structuring the Technology dimension within an Education 5.0 framework, despite varying degrees of consensus intensity regarding specific items. This consistent recognition establishes the Technology dimension as a foundational pillar, where the predominance of high scores highlights that experts view technological literacy, analytics, and adaptive infrastructure not merely as operational tools, but as fundamental enablers for building human-centered, data-driven ecosystems. In its current form, this dimension positions technology as a true catalyst for innovation, collaboration, and inclusion — an instrument essential for expanding human potential and promoting a sustainable, equitable future in higher education. Table 5 shows the elements evaluations of the Technology dimension.

Technology Dimension	1 – Not important		2 – Slightly important		3 – Important		4 – Very important		5 – Extremely important		9 – Unable to give an opinion		Total		WA
Responsible and Sustainable Tech Training	0,00%	0	1,85%	1	9,26%	5	20,37%	11	62,96%	34	5,56%	3	100%	54	4,5
High-Speed Networks	0,00%	0	3,70%	2	12,96%	7	31,48%	17	50,00%	27	1,85%	1	100%	54	4,3
AI Literacy and Computational Thinking	1,85%	1	1,85%	1	7,41%	4	37,04%	20	44,44%	24	7,41%	4	100%	54	4,3
Smart Infrastructure for Adaptive, Technology-Enhanced Learning	0,00%	0	1,85%	1	14,81%	8	35,19%	19	42,59%	23	5,56%	3	100%	54	4,3
Data-Driven Decision Making	0,00%	0	1,85%	1	18,52%	10	31,48%	17	40,74%	22	7,41%	4	100%	54	4,2
Access to Cutting-Edge Technologies	0,00%	0	3,70%	2	18,52%	10	31,48%	17	44,44%	24	1,85%	1	100%	54	4,2
Blockchain for Credentials and Cybersecurity	0,00%	0	1,85%	1	24,07%	13	16,67%	9	42,59%	23	14,81%	8	100%	54	4,2
Sustainability and SDG Literacy through Green and Digital Technologies	1,85%	1	5,56%	3	20,37%	11	22,22%	12	46,30%	25	3,70%	2	100%	54	4,1
Hybrid Learning	0,00%	0	1,85%	1	25,93%	14	31,48%	17	37,04%	20	3,70%	2	100%	54	4,1
AI-Enhanced Ecosystems	0,00%	0	5,56%	3	16,67%	9	38,89%	21	31,48%	17	7,41%	4	100%	54	4,0
Learning Analytics and AI Support	1,85%	1	5,56%	3	20,37%	11	33,33%	18	31,48%	17	7,41%	4	100%	54	3,9
Gamification	1,85%	1	9,26%	5	25,93%	14	29,63%	16	25,93%	14	7,41%	4	100%	54	3,7
Augmented and Virtual Reality (AR/VR)	3,70%	2	7,41%	4	38,89%	21	27,78%	15	16,67%	9	5,56%	3	100%	54	3,5
TOTAL	0,85%	6	3,99%	28	19,52%	137	29,77%	209	39,74%	279	6,13%	43	100%	702	4,1

Table 5: Technology dimension and its elements evaluation

Source: Author.

Note: WA (weighted average).

The Technology Dimension comprises 13 elements evaluated by the participants. The survey results indicate a strong consensus on the necessity of ethical training and robust infrastructure as foundational layers for Education 5.0 in higher education institutions. Responsible and Sustainable Tech Training emerged as the most critical element, achieving the highest Weighted Average (WA) of 4.5. This result suggests that participants prioritize the human and ethical aspects of technology over the tools themselves. This aligns with the perspective of Alves Guimarães *et al.*, (2023) and Peláez-Sánchez *et al.* (2024), who argue that integrating environmental integrity, social responsibility, and economic viability into technological education is essential. By doing so, institutions empower learners to make informed decisions for a just and sustainable future.

Following closely, High-Speed Networks (WA = 4.3) were validated as a fundamental requirement. Participants recognize that without this backbone, advanced educational methodologies fail. This supports the findings of Ahmad *et al.* (2023), who state that high-speed networks are essential for the real-time delivery of digital resources, enabling seamless communication and collaboration between students, teachers, and educational institutions. Similarly, AI Literacy and Computational Thinking (WA = 4.3) was deemed highly important. In the context of technological courses, respondents indicated that understanding the logic behind AI is as crucial as using it. This corroborates Felcher *et al.*, (2022) and Supriya *et al.* (2024), who emphasize that these skills must be woven into curricula to empower students to understand, use, and critically assess tools such as GenAI for research and problem-solving. The participants also highlighted the importance of Smart Infrastructure for Adaptive, Technology-Enhanced Learning (WA = 4.3). This suggests a demand for learning environments that bridge the physical and digital divide. As noted by Ciolacu *et al.* (2024) and Supriya *et al.* (2024), integrating cloud-based GenAI tools with IoT-enabled smart classrooms allows for secure, adaptive, and interactive learning experiences under effective governance.

Data-Driven Decision Making (WA = 4.2) was validated as a key managerial and pedagogical tool. Participants acknowledge that Education 5.0 relies on evidence rather than intuition. This is consistent with Ahmad *et al.* (2023), who explain that DDDM involves using metrics to assess student outcomes, learning analytics, and return on investment to guide institutional improvements. Regarding practical application, Access to Cutting-Edge Technologies (WA = 4.2) remains a priority for

productive ecosystems. Participants indicated that access to tools like 3D printers and VR/AR headsets is vital for designing real-world systems. Ciolacu *et al.* (2024) and Souza & Debs (2024) reinforce this, noting that GenAI further enhances this access through inclusivity features like voice/text generation. Blockchain for Credentials and Cybersecurity (WA = 4.2) was also rated highly, reflecting growing concerns over data integrity in the digital age. This validates the stance of Ciolacu *et al.* (2024) and Supriya *et al.* (2024) that blockchain is necessary to ensure secure and verifiable academic records, guaranteeing the safety of student data and certifications.

The survey shows that Sustainability and SDG Literacy through Green and Digital Technologies (WA = 4.1) is a relevant concern for respondents. This indicates an awareness of the environmental impact of digital transformation. Alves Guimarães *et al.* (2023) and Peláez-Sánchez *et al.* (2024) support this view, emphasizing that technology must align with sustainable development goals (SDGs) and broader social concerns. Hybrid Learning (WA = 4.1) continues to be valued for its flexibility. Participants view the blending of online and in-person modalities as a standard for personalized education, a concept supported by Alves Guimarães *et al.*, (2023); Maria *et al.*, (2021); and Rahim, (2021) as a way to accommodate diverse learning needs.

The integration of AI-Enhanced Ecosystems (WA = 4.0) into Learning Management Systems (LMS) was recognized as important for modernizing assessment. According to Agarwal *et al.* (2025) and Ciolacu *et al.* (2024), these ecosystems are crucial for enhancing formative assessment, content generation, and enabling collaborative co-creation processes. Learning Analytics and AI Support (WA = 3.9), while scoring slightly lower, is still considered important for personalization. Participants indicate that AI-driven advisory systems are useful for customizing learning pathways. Ciolacu *et al.* (2024) and Maria *et al.*, (2021) agree that these tools provide essential real-time performance updates.

Gamification (WA = 3.7) was viewed as a specific methodological strategy to drive engagement. While not ranked as high as infrastructure, it is validated by Ciolacu *et al.* (2024) and Souza & Debs (2024) as an effective way to increase motivation and demonstrate the applicability of engineering concepts in the real world. Finally, Augmented and Virtual Reality (AR/VR) received a WA of 3.5. Although this is the lowest score in this dimension, it remains a relevant tool for specific scenarios. Participants acknowledge its utility for immersive experiences, which Felcher *et al.*,

(2022) and Souza & Debs (2024) note are essential for virtual labs and scenario-based simulations that enhance interaction with complex systems.

4.2.3. Skill Dimension

Each of the 10 elements within the Skills dimension was evaluated using the Delphi method, consensus is generally recognized when 70% to 80% of experts converge within the higher-relevance categories, and when less than 10% of the responses fall within the rejection range (Barrios *et al.*, 2021). The results revealed a strong level of agreement among the 54 respondents. Overall, 45.0% (243 ratings) classified the skills-related elements as Extremely important, followed by 30.7% (166 ratings) as Very important and 13.7% (74 ratings) as Important. Only 7.2% (13 ratings) were evaluated as Slightly important, 1.3% (7 ratings) as Not important, and 6.8% (37 ratings) as No conditions for an opinion. These results demonstrate a clear concentration of responses in the upper categories, indicating high consensus on the relevance of the Skills dimension for Education 5.0.

All elements achieved a weighted average (WA) ≥ 3.6 , and eight of the ten elements reached WA ≥ 4.0 , meeting the criterion of high relevance and strong expert consensus. The remaining two elements — Collaboration with AI (WA = 3.9) and Adaptability to VUCA/BANI/RUPT Worlds (WA = 3.6) still met the Delphi requirement for moderate consensus ($\geq 70\%$) with low rejection rates, confirming their overall acceptance and importance.

Among the highest-rated components, Analytical and Critical Thinking (WA = 4.6), Socioemotional Competencies (WA = 4.5), Cognitive and Socioemotional Skills for 21st-Century Professionals (WA = 4.5), and Integration of Human and Technical Skills (WA = 4.5) emerged as the strongest indicators of the dimension. These results highlight the panel's emphasis on combining analytical reasoning, emotional intelligence, and the integration of human and technical capabilities as foundational competencies for Education 5.0.

Other important elements included Digital Citizenship and Expanded Digital Ethics (WA = 4.3) and Lifewide, Self-Directed, Meta-Learning (WA = 4.1), and Collaboration and Industry Engagement (WA = 4.0 which reinforce the growing need for ethical digital behavior and continuous learning in increasingly technology-intensive educational environments. Elements with comparatively lower averages, such as),

Collaboration with AI (WA = 3.9), and Adaptability to VUCA/BANI/RUPT Worlds (WA = 3.6), although still positively evaluated, suggest areas where competencies may require further development or institutional investment to be fully integrated into current educational practices.

Overall, the findings indicate that the Skills dimension is strongly validated, with nearly 90% of participants rating at least one skill-related element as Important, Very important, or Extremely important. The predominance of high scores demonstrates widespread recognition of skills such as critical thinking, socioemotional development, digital ethics, and adaptive learning as essential pillars of Education 5.0. These results confirm that the Skills dimension plays a central role in shaping human-centered, future-oriented, and resilient learning ecosystems, where learners must navigate complexity, collaborate with intelligent systems, and continuously develop new capacities to thrive in rapidly evolving technological and social environments. Table 6 shows the elements evaluations of the Skills dimension.

Skill Dimension	1 – Not important		2 – Slightly important		3 – Important		4 – Very important		5 – Extremely important		9 – Unable to give an opinion		Total		WA
Analytical and Critical Thinking	0,00%	0	1,85%	1	3,70%	2	24,07%	13	62,96%	34	7,41%	4	100%	54	4,6
Socioemotional Competencies	1,85%	1	0,00%	0	5,56%	3	27,78%	15	61,11%	33	3,70%	2	100%	54	4,5
Cognitive and Socioemotional Skills for 21st-Century Professionals	1,85%	1	0,00%	0	7,41%	4	25,93%	14	59,26%	32	5,56%	3	100%	54	4,5
Integration of Human and Technical Skills	1,85%	1	0,00%	0	7,41%	4	27,78%	15	57,41%	31	5,56%	3	100%	54	4,5
Complex Problem-Solving	0,00%	0	0,00%	0	12,96%	7	35,19%	19	44,44%	24	7,41%	4	100%	54	4,3
Digital Citizenship and Expanded Digital Ethics	0,00%	0	1,85%	1	14,81%	8	31,48%	17	46,30%	25	5,56%	3	100%	54	4,3
Lifewide, Self-Directed, and Meta-Learning	0,00%	0	1,85%	1	24,07%	13	29,63%	16	40,74%	22	3,70%	2	100%	54	4,1
Collaboration and Industry Engagement	1,85%	1	7,41%	4	14,81%	8	38,89%	21	33,33%	18	3,70%	2	100%	54	4,0
Collaboration with AI	1,85%	1	5,56%	3	20,37%	11	42,59%	23	27,78%	15	1,85%	1	100%	54	3,9
Adaptability to VUCA/BANI/RUPT Worlds	3,70%	2	5,56%	3	25,93%	14	24,07%	13	16,67%	9	24,07%	13	100%	54	3,6
TOTAL	1,30%	7	2,41%	13	13,70%	74	30,74%	166	45,00%	243	6,85%	37	100%	540	4,2

Table 6: Skill dimension and its elements evaluation

Source: Author.

Note: WA (weighted average).

The Skill Dimension, composed of 10 elements, reveals a clear trend among respondents: while technical proficiency is assumed, the "human" skills such as critical thinking, emotional intelligence, and ethical judgment are viewed as the true differentiators in an AI-saturated landscape. Analytical and Critical Thinking stands out as the most vital element, achieving the highest Weighted Average (WA) of 4.6. In the context of technological education, participants indicate that this skill is paramount because it safeguards against the passive consumption of technology. This aligns with Ciolacu *et al.* (2024) and Maria *et al.*, (2021), who argue that students must develop the capacity to assess AI outputs, mitigate over-reliance, and strictly maintain human judgment in decision-making processes.

Following closely, three elements tied with a WA of 4.5, reinforcing the human-centric focus of Education 5.0. First, Socioemotional Competencies were validated as essential. Participants recognize that professional growth relies heavily on non-technical traits. This supports the view of Felcher *et al.*, (2022) and Souza & Medeiros Neta, (2021), who emphasize that communication, empathy, teamwork, and emotional management are critical for enhancing personal and professional development.

Second, the Cognitive and Socioemotional Skills for 21st-Century Professionals were deemed extremely important. This suggests that respondents see cognitive flexibility and creativity as survival skills for the future. As noted by Alves Guimarães *et al.* (2023), Peláez-Sánchez *et al.* (2024), and UNESCO (2021), these skills complement technological proficiency, enabling graduates to thrive in complex, changing environments.

Third, the Integration of Human and Technical Skills highlights the need for synergy. Participants indicated that technical knowledge in isolation does not fully meet the requirements for the development of a teacher or student. This corroborates Alves Guimarães *et al.* (2023) and Peláez-Sánchez *et al.* (2024), who state that the real value lies in the union of these domains, making empathy and resilience as fundamental as technical expertise.

Complex Problem-Solving (WA = 4.3) was also highly rated. In the context of engineering and technology courses, this reflects the need for practical application. Agarwal *et al.* (2025) and Maria and Supriya *et al.* (2024) point out that this involves training students to solve multifaceted, real-world problems using AI-augmented tools within human-centric frameworks.

Similarly, Digital Citizenship and Expanded Digital Ethics (WA = 4.3) is considered a key competency. Participants validated that ethical use goes beyond mere compliance. Ciolacu *et al.* (2024) and Supriya *et al.* (2024) explain that this requires skills in prompt engineering and detecting AI bias to ensure responsible application that addresses privacy and fairness. Lifewide, Self-Directed, and Meta-Learning (WA = 4.1) reflects the changing nature of knowledge retention. Participants acknowledge that the ability to "learn how to learn" is crucial. This is supported by Ciolacu *et al.* (2024) and Gartner (2025), who note that as GenAI enables anytime, anywhere learning, students must foster the capacity to learn, unlearn, and relearn.

Collaboration and Industry Engagement (WA = 4.0) emphasizes the external connection of the university. Respondents view the building of communities of practice as important. Ciolacu *et al.* (2024) and Supriya *et al.* (2024) confirm that this co-development of skills with the industry is relevant to keeping pace with emerging job markets. Collaboration with AI (WA = 3.9) suggests that while working with tools is important, it ranks lower than the foundational thinking skills mentioned earlier. Nonetheless, Supriya *et al.* (2024) and Ahmad (2023) highlight its role in enhancing productivity and creating personalized learning paths based on student accomplishments.

Finally, Adaptability to VUCA/BANI/RUPT Worlds received a WA of 3.6. While it presents the lowest average in this dimension, it is still a relevant concern. Ciolacu *et al.* (2024) and Felcher *et al.*, (2022) argue that developing robust skill sets is necessary to prepare students to withstand these volatile, uncertain, complex, and ambiguous contexts.

4.2.4. Innovation Dimension

Each of the 12 elements within the Innovation dimension was evaluated using the Delphi method, consensus is normally achieved when 70% to 80% of experts converge within the higher categories of the scale. (Barrios *et al.*, 2021). The analysis showed a strong level of expert agreement. Across the Innovation dimension, 45.8% (297 ratings) classified the elements as Extremely important, followed by 29.9% (194 ratings) as Very important and 14.8% (96 ratings) as Important. By comparison, only 2.3% (15 ratings) selected Slightly important, 1.3% (9 ratings) chose Not important, and 5.7% (37 ratings) indicated No conditions for an opinion. These results

demonstrate a clear concentration of responses in the upper categories, confirming the high perceived relevance of innovation-oriented practices for Education 5.0.

All Innovation elements presented weighted averages (WA) between 4.0 and 4.6, indicating strong or moderate consensus across the entire set. Eleven of the twelve elements achieved $WA \geq 4.1$, meeting the criterion for high relevance, while Generative AI for Co-creation and Applied Research, although slightly lower ($WA = 4.0$), still demonstrated moderate consensus with low rejection rates ($<10\%$), confirming its overall acceptance by the expert panel.

Among the strongest elements, Reflective and Collaborative Teaching ($WA = 4.6$), Inclusion, Sustainability, and Societal Impact ($WA = 4.5$), and Problem-Based and Scenario-Based Learning ($WA = 4.5$) were the highest-rated components. These results underline the centrality of reflective pedagogies, sustainability principles, and authentic, real-world learning strategies in shaping innovative educational ecosystems.

Other well-evaluated elements included Technology-Enhanced Learning Analytics ($WA = 4.3$), Neuroscience ($WA = 4.3$), and Personalized and Adaptive Learning ($WA = 4.2$), reflecting the growing recognition of data-informed, neuroeducation-based, and adaptive instructional models as drivers of educational transformation. Elements such as Maker and Living Labs ($WA = 4.1$), Non-Traditional Labs ($WA = 4.1$), Open Innovation and Productive Sector Collaboration ($WA = 4.1$), Active Methodologies ($WA = 4.1$), and Biofeedback for Well-being ($WA = 4.1$) also demonstrated strong consensus, emphasizing the importance of experiential, multidisciplinary, and human-centered innovation practices. Although Generative AI for Co-creation and Applied Research ($WA = 4.0$) was the lowest-scoring element, it was still positively evaluated by the majority of experts, indicating early adoption tendencies and a growing interest in AI-enabled creativity within higher education. Its slightly lower WA may reflect ongoing challenges related to technical expertise, infrastructure, or ethical concerns, which are typical of emerging technologies.

Overall, the results confirm that the Innovation dimension is strongly validated, with nearly 90% of participants rating at least one innovation-related element as Important, Very important, or Extremely important. This distribution highlights a robust recognition that innovative pedagogies, collaborative knowledge creation, data-informed practices, and emerging technologies form a crucial foundation for Education 5.0. The dimension positions innovation not merely as a set of isolated practices but as a systemic driver that connects pedagogy, technology, ethics, and societal impact.

Within this perspective, innovation becomes a catalyst for creating learning environments that are adaptive, interdisciplinary, sustainable, and aligned with human-centered and future-oriented transformations in higher education. Table 7 shows the elements evaluations of the Innovation dimension.

Innovation Dimension	1 – Not important		2 – Slightly important		3 – Important		4 – Very important		5 – Extremely important		9 – Unable to give an opinion		Total		WA
Reflective and Collaborative Teaching	1,85%	1	0,00%	0	3,70%	2	25,93%	14	64,81%	35	3,70%	2	100%	54	4,6
Inclusion, Sustainability, and Societal Impact	1,85%	1	1,85%	1	7,41%	4	18,52%	10	61,11%	33	9,26%	5	100%	54	4,5
Problem-Based and Scenario-Based Learning	0,00%	0	0,00%	0	11,11%	6	27,78%	15	57,41%	31	3,70%	2	100%	54	4,5
Technology-Enhanced Learning Analytics	0,00%	0	3,70%	2	12,96%	7	33,33%	18	46,30%	25	3,70%	2	100%	54	4,3
Neuroscience	0,00%	0	0,00%	0	20,37%	11	31,48%	17	44,44%	24	3,70%	2	100%	54	4,3
Personalized and Adaptive Learning	0,00%	0	1,85%	1	22,22%	12	29,63%	16	44,44%	24	1,85%	1	100%	54	4,2
Non-Traditional Labs	0,00%	0	3,70%	2	20,37%	11	29,63%	16	40,74%	22	5,56%	3	100%	54	4,1
Maker and Living Labs	1,85%	1	3,70%	2	22,22%	12	22,22%	12	48,15%	26	1,85%	1	100%	54	4,1
Biofeedback for Well-being	3,70%	2	0,00%	0	11,11%	6	38,89%	21	33,33%	18	12,96%	7	100%	54	4,1
Open Innovation and Productive Sector Collaboration	3,70%	2	3,70%	2	12,96%	7	35,19%	19	37,04%	20	7,41%	4	100%	54	4,1
Active Methodologies	3,70%	2	5,56%	3	12,96%	7	35,19%	19	40,74%	22	1,85%	1	100%	54	4,1
Generative AI for Co-creation and Applied Research	0,00%	0	3,70%	2	20,37%	11	31,48%	17	31,48%	17	12,96%	7	100%	54	4,0
TOTAL	1,39%	9	2,31%	15	14,81%	96	29,94%	194	45,83%	297	5,71%	37	100%	648	4,2

Table 7: Innovation dimension and its elements evaluation

Source: Author.

Note: WA (weighted average).

The Innovation Dimension, composed of 12 elements, highlights a shift in the perceived drivers of educational progress. The results indicate that respondents value the philosophy and impact of teaching methods (collaboration, inclusion) slightly higher than the specific tools (Generative AI, Labs) used to achieve them. Reflective and Collaborative Teaching achieved the highest Weighted Average (WA) of 4.6. In the context of technological education, this suggests that the human element remains central to innovation. Participants view the educator's ability to critically reflect on AI's role and foster collaboration as indispensable. This supports Gartner (2025) and Shailendra *et al.* (2024), who argue that educators and citizen developers must serve as bridges between real-world needs and institutional technology to drive genuine innovation.

Following closely, Inclusion, Sustainability, and Societal Impact and Problem-Based and Scenario-Based Learning both received a WA of 4.5, underscoring the social mandate of Education 5.0. Regarding Inclusion, Sustainability, and Societal Impact, participants indicated that innovation is not purely technological but also social and cultural. This aligns with Oliveira *et al.*, (2023), Ciolacu *et al.* (2023), and UNESCO (2021), who emphasize the need for an inclusive mindset that blends technology with societal responsibility to reflect evolving industrial parameters.

Similarly, Problem-Based and Scenario-Based Learning was validated as a critical active learning model. Respondents recognize the value of shifting toward competency-based approaches where students solve real-world problems. Ciolacu *et al.* (2024) and Maria *et al.*, (2021) support this, noting that GenAI and AR/VR tools effectively support summarization, ideation, and hypothesis exploration in these scenarios. Technology-Enhanced Learning Analytics (WA = 4.3) was also rated highly. Participants acknowledge that data is essential for optimization. This corroborates Ciolacu *et al.* (2024) and (Souza & Debs, 2024), who state that AI-driven analytics provide the necessary insights to track progress and optimize teaching methods.

Neuroscience (WA = 4.3) emerged as a significant element, indicating an interest in the biological basis of learning. Participants validated the application of brain science to design better strategies. Felcher *et al.*, (2022) and Maria *et al.*, (2021) reinforce this, explaining that these insights are key to enhancing emotional engagement and learning efficacy. Personalized and Adaptive Learning (WA = 4.2) reflects the demand for customized education. Respondents value the use of AI to recommend courses based on individual strengths. Shailendra *et al.* (2024) and Souza

& Debs (2024) confirm that this approach supports flexible curricula and low-code/no-code projects that enable experimentation.

A cluster of five elements followed, all with a WA of 4.1, indicating a solid consensus on their importance as practical drivers of innovation. Non-Traditional Labs (WA = 4.1) were recognized for shifting learning from conventional to virtual environments. Ciolacu *et al.* (2024) and Supriya *et al.* (2024) explain that these makerspaces and virtual labs support interdisciplinary learning and brainstorming with direct practical applications. Maker and Living Labs (WA = 4.1) were similarly valued for their collaborative nature. Ciolacu *et al.* (2023) note that these spaces employ design thinking and agile methods to develop students' creativity and sustainable innovation.

Biofeedback for Well-being (WA = 4.1) highlights the growing concern for student health. Participants indicated that monitoring well-being is part of the educational responsibility. Agarwal *et al.* (2025) and Ciolacu *et al.* (2024) state that AI-driven mental health monitoring necessitates educators' upskilling to support this "human-centered" aspect of Education 5.0. Open Innovation and Productive Sector Collaboration (WA = 4.1) emphasizes the need for external partnerships. Caratozzolo *et al.*, (2022) validate this, pointing out that immersing students in authentic contexts with industry partners fosters co-creation across academia and business. Active Methodologies (WA = 4.1) were acknowledged as standard pedagogical strategies. Maria *et al.*, (2021) and Souza & Medeiros Neta (2021) affirm that strategies like flipped classrooms are essential to foster student protagonism and critical engagement.

Finally, Generative AI for Co-creation and Applied Research received a WA of 4.0. While crucial, it ranked slightly lower than the human-centric elements, possibly indicating it is seen as a facilitator rather than a driver. Shailendra *et al.* (2024) support its role in expanding possibilities for teamwork, prototyping, and solution design.

4.2.5. Elements of Education 4.0 validated for the evolution of Education 5.0

Figure 11 presents a visual representation of the three validated dimensions of Education 5.0 - Technology, Skill, and Innovation - each organized into a distinct column with its respective key elements. Together, these 35 elements illustrate how

the dimensions integrate to form a comprehensive, future-ready educational framework that supports digital transformation, human development, and innovative learning ecosystems.

Technology	Skill	Innovation
• Main elements • Responsible and Sustainable Tech Training • High-Speed Networks • AI Literacy and Computational Thinking • Smart Infrastructure for Adaptive, Technology-Enhanced Learning • Data-Driven Decision Making • Access to Cutting-Edge Technologies • Blockchain for Credentials and Cybersecurity • Sustainability and SDG Literacy through Green and Digital Technologies • Hybrid Learning • AI-Enhanced Ecosystems • Additional elements • Learning Analytics and AI Support • Gamification • Augmented and Virtual Reality (AR/VR)	• Main elements • Analytical and Critical Thinking • Socioemotional Competencies • Cognitive and Socioemotional Skills for 21st-Century Professionals • Integration of Human and Technical Skills • Complex Problem-Solving • Digital Citizenship and Expanded Digital Ethics • Lifewide, Self-Directed, and Meta-Learning • Collaboration and Industry Engagement • Additional elements • Collaboration with AI • Adaptability to VUCA/BANI/RUPT Worlds	• Main elements • Reflective and Collaborative Teaching • Inclusion, Sustainability, and Societal Impact • Problem-Based and Scenario-Based Learning • Technology-Enhanced Learning Analytics • Neuroscience • Personalized and Adaptive Learning • Non-Traditional Labs • Maker and Living Labs • Biofeedback for Well-being • Open Innovation and Productive Sector Collaboration • Active Methodologies • Generative AI for Co-creation and Applied Research

Figure 11: The dimensions and the elements validated for Education 5.0.

Source: Author.

5. CONCLUSIONS

The accelerated advancement of digital technologies, particularly Artificial Intelligence (AI), the Internet of Things (IoT), and Generative Artificial Intelligence (GenAI), has redefined contemporary educational paradigms and intensified the transition from Education 4.0 to Education 5.0. In developing countries such as Brazil, this transition occurs within a context marked by structural inequalities, limited infrastructure, and persistent challenges in preparing educators for emerging demands. Technological Higher Education Institutions (THEIs) play a central role in this transformation because they prepare professionals who will work in technologically intensive and innovation-driven environments.

Education 4.0 introduced principles aligned with digitalization, automation, and data-driven teaching. However, the emergence of Education 5.0 requires an expanded focus on human-centered values, ethical technology use, socioemotional competencies, sustainability, and personalized learning. These elements reflect a new educational vision aligned with the principles of Industry 5.0. The contextualization of Education 4.0 within the Education 5.0 paradigm in Brazilian THEIs highlights both the importance of technological modernization and the urgency of building learning ecosystems that are technologically advanced and human-centered.

In Brazil, the adoption of Education 5.0 is challenged by significant technological and pedagogical limitations. Many higher education institutions in developing countries lack basic ICT infrastructure, and this scenario is commonly seen in Brazilian THEIs. At the same time, the integration of GenAI into education creates new opportunities for personalization, automation, and innovative learning experiences. These opportunities coexist with critical gaps in educator preparation, digital literacy, ethical governance, and institutional readiness. This situation reinforces the need for structured frameworks that guide a gradual and context-sensitive transition toward Education 5.0. By examining this transition through the lens of Education 4.0 frameworks, this dissertation positions Education 5.0 as both necessary and feasible within Brazilian THEIs.

Five consolidated Education 4.0 frameworks supported the development of this study. These include Digital Education Ecosystems (DEEs), the Malaysian Higher Education 4.0 Framework, the STEM Learning Framework, the TADEO Model, and the World Economic Forum Education 4.0 Framework.

From these models, three analytical dimensions were extracted and identified as Technology, Skills, and Innovation. This process resulted in an initial set of 27 elements that guided the construction of the research instrument. Based on the findings from the literature review and the evaluation of the three experts, the structure was expanded and refined, resulting in a total of 35 elements, including eight new elements added from the theoretical foundation.

The expert committee composed by of 54 PhD researchers reviewed the material and provided their assessments to support the validation, clarity, and relevance of the proposed structure. Agreement levels frequently surpassed 80 percent and demonstrated consistent expert recognition of the importance of transitioning from digitally centered models to human-centered and AI-supported educational ecosystems.

A key objective is to identify and characterize the main elements of current Education 4.0 frameworks that could facilitate the adoption of Education 5.0 in Technological Higher Education Institutions in Brazil. The Technology dimension presented 13 elements. Elements such as Responsible and Sustainable Tech Training, AI Literacy and Computational Thinking, Smart Infrastructure for Adaptive, Technology-Enhanced Learning, High-Speed Networks, and AI-Enhanced Ecosystems emerged as the highest-rated and most strongly validated components of the Technology dimension. Conversely, Learning Analytics and AI Support, Gamification, and Augmented and Virtual Reality (AR/VR), although slightly below the 4.0 threshold, still demonstrated moderate expert agreement and low rejection rates, confirming that these elements remain relevant but were comparatively less prioritized by the panel.

The Skills dimension presented 10 elements. Among the highest-rated components, Analytical and Critical Thinking, Socioemotional Competencies, Cognitive and Socioemotional Skills for 21st-Century Professionals, and Integration of Human and Technical Skills emerged as the strongest indicators of the dimension. These results highlight the panel's emphasis on combining analytical reasoning, emotional intelligence, and the integration of human and technical capabilities as foundational competencies for Education 5.0. Other important elements included Digital Citizenship and Expanded Digital Ethics and Lifewide, Self-Directed, Meta-Learning, and Collaboration and Industry Engagement which reinforce the growing need for ethical digital behavior and continuous learning in increasingly technology-

intensive educational environments. Elements with comparatively lower averages, such as, Collaboration with AI, and Adaptability to VUCA/BANI/RUPT Worlds, although still positively evaluated, suggest areas where competencies may require further development or institutional investment to be fully integrated into current educational practices.

In the Innovation dimension, with 12 elements, the most relevant elements included Reflective and Collaborative Teaching, Inclusion, Sustainability, and Societal Impact, and Problem-Based and Scenario-Based Learning were the highest-rated components. Other well-evaluated elements included Technology-Enhanced Learning Analytics, Neuroscience, and Personalized and Adaptive Learning, reflecting the growing recognition of data-informed, neuroeducation-based, and adaptive instructional models as drivers of educational transformation. Elements such as Maker and Living Labs, Non-Traditional Labs, Open Innovation and Productive Sector Collaboration, Active Methodologies, and Biofeedback for Well-being also demonstrated strong consensus, emphasizing the importance of experiential, multidisciplinary, and human-centered innovation practices. Although Generative AI for Co-creation and Applied Research was the lowest-scoring element, it was still positively evaluated by the majority of experts, indicating early adoption tendencies and a growing interest in AI-enabled creativity within higher education.

This research offers important contributions to the academic community. It fills a documented gap by connecting Education 4.0 frameworks to Education 5.0 in the context of developing countries, a theme that remains underexplored in the literature. It also contributes methodologically by combining a Systematic Literature Review, expert validation, and structured analysis, producing dimensions and elements of the Education 4.0 that can be applied in an Education 5.0 framework in future studies. Additionally, it advances theoretical understanding by proposing a validated set of 35 elements specifically adapted to the needs of Brazilian THEIs. The study also strengthens the dialogue between Industry 4.0, Industry 5.0, and higher education, and demonstrates how educational systems can respond strategically to rapid technological changes.

For professors, coordinators, managers, and employees in Brazilian Technological Higher Education Institutions, and also to public employees and managers and other professionals involved in public policy development, the study provides practical contributions. The validated elements offer a clear roadmap for

guiding technological investments, curriculum redesign, and educator training aligned with Education 5.0. The results can support institutional policies for responsible integration of AI and GenAI, encourage interdisciplinary collaboration, and strengthen partnerships between academia and industry. The identified dimensions and elements also support the development of smart infrastructures, adaptive curricula, and pedagogical models that promote socioemotional development and lifewide learning.

Despite its contributions, the study presents limitations. The geographical focus on Brazil restricts generalization to other developing regions with different socioeconomic realities. The reliance on consulted expert perceptions is not able to capture the practical implementation of the validated elements in real-world scenarios, since the experts participating in the research work as professors with doctorates and researchers in the teaching of professional education at the master's and doctoral level. The research also does not include longitudinal data capable of measuring impacts on learning outcomes, institutional performance, or student competencies.

Future research may advance this work in three ways. First, the dimensions and elements identified in this study can be validated as a complete Education 5.0 framework through qualitative research using multivariate analysis, such as SPSS or Photon. Second, the dimensions and elements may be implemented and validated in real-world situations, particularly within technical schools experienced in professional education, to assess their practical applicability. Third, the dimensions and elements can be analyzed and validated in different countries, enabling cross-national comparison and expanding the framework's relevance beyond the Brazilian context.

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APPENDIX A

QUESTIONARE

Pesquisa sobre frameworks da Educação 4.0 e IA como suporte à Educação 5.0 em Instituições de Ensino Superior Tecnológico no Brasil

Apresentação

Prezado(a) Prof(a). Dr(a).:

Meu nome é Emilia Augusta Rego, sou mestranda no Programa de Pós-Graduação em Informática e Gestão do Conhecimento da Universidade Nove de Julho, sob orientação do Prof. Dr. Marcos Antonio Gaspar.

Venho, por meio desta, convidá-lo(a) a participar como especialista na temática abordada em minha pesquisa de dissertação. O objetivo da pesquisa é identificar e priorizar os principais componentes dos atuais frameworks de Educação 4.0 que podem facilitar a adoção da Educação 5.0 Instituições de Ensino Superior Tecnológico no Brasil. A sua expertise e experiência profissional nessa área são de grande valor e certamente contribuirão de forma significativa para o avanço do conhecimento nesse campo.

A participação consiste no preenchimento de um questionário, com tempo estimado de 10 a 12 minutos. Ressalto que todas as respostas serão tratadas de forma anônima, garantindo o sigilo e a confidencialidade dos participantes e instituições. Os dados serão utilizados exclusivamente para fins acadêmicos, e nenhuma identificação individual ou institucional será divulgada nos resultados da dissertação.

O questionário pode ser acessado e respondido logo abaixo.

Agradeço, desde já, pelo seu tempo e colaboração.
Atenciosamente,

Emilia Augusta Rego

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Para responder as perguntas subsequentes, por favor, considere os seguintes conceitos:

Transformação Digital (TD): envolve a integração de tecnologias digitais em todas as áreas de uma organização, reformulando operações, processos e a entrega de valor. No contexto educacional, a TD exige adaptação contínua às tendências tecnológicas, mesmo diante de desafios como a infraestrutura digital inadequada e a resistência à mudança por parte de gestores e docentes (Ciolacu *et al.*, 2024; Oliveira; de Souza, 2021).

Educação 4.0: alinhada à Quarta Revolução Industrial, a Educação 4.0 enfatiza o uso de tecnologias avançadas (como Inteligência Artificial, Realidade Virtual, Internet das Coisas e robótica) e metodologias ativas para promover a aprendizagem personalizada, o desenvolvimento de habilidades do século XXI, criatividade, pensamento crítico e colaboração (Chituc, 2022a).

Educação 5.0: lançada em 2020, a Educação 5.0 propõe um modelo educacional mais centrado no ser humano, com forte integração entre tecnologias (IA, TIC, IoT) e habilidades socioemocionais. Ela se baseia nos avanços da Educação 4.0, mas avança ao integrar pilares como saúde, bem-estar, sustentabilidade, empatia e ética, alinhando-se à lógica da Indústria 5.0 (FELCHER; BLANCO; FOLMER, 2022)

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OLIVEIRA, Katyeudo K. de S.; DE SOUZA, Ricardo A. C. Digital Transformation towards Education 4.0. *Informatics in Education*, [S. l.], 2021. DOI: 10.15388/infedu.2022.13.

FELCHER, Carla Denize Ott; BLANCO, Gisele Silveira; FOLMER, Vanderlei. Educação 5.0: uma sistematização a partir de estudos, pesquisas e reflexões.

Nesta pesquisa, o framework a ser desenvolvido está organizado em três dimensões principais: Tecnologia, Competências e Inovação, conforme expostas no Quadro 1. Cada dimensão contempla elementos essenciais para a implementação

efetiva da Educação 5.0 no contexto das Instituições de Ensino Superior Tecnológico no Brasil, contemplando assim 35 elementos distribuídos nas três dimensões indicadas.

Tecnologia	Competências	Inovação
Alfabetização em IA e Pensamento Computacional Ecossistemas Aprimorados por IA Acesso a Tecnologias de Ponta Realidade Aumentada e Virtual (AR/VR) Infraestrutura Inteligente para Aprendizagem Adaptativa e Mediadas por Tecnologia Analítica da Aprendizagem e Apoio de IA Blockchain para credenciais e segurança cibernética Redes de Alta Velocidade Tomada de Decisão Orientada por Dados Gamificação Aprendizado híbrido Sustentabilidade e Letramento em ODS por meio de Tecnologias Verdes e Digitais Formação Tecnológica Responsável e Sustentável	Pensamento Analítico e Crítico Colaboração com IA Cidadania Digital e Ética Digital Ampliada Resolução de Problemas Complexos Colaboração e Engajamento com o Setor Produtivo Adaptabilidade aos Mundos VUCA/BANI/RUPT Aprendizagem ao Longo da Vida, Autodirigida e Metacompetências Competências Socioemocionais Integração de Habilidades Humanas e Técnicas Competências Cognitivas e Socioemocionais para Profissionais do Século XXI	Aprendizagem Personalizada e Adaptativa Aprendizagem Baseada em Problemas e em Cenários Tecnologias de Apoio à Analítica da Aprendizagem Laboratórios Não Tradicionais Biofeedback para Monitoramento do Bem-Estar Estudantil Ensino Reflexivo e Colaborativo Metodologias ativas Neurociência aplicada à educação Inovação Aberta e Colaboração com o Setor Produtivo IA Generativa para Cocriação e Pesquisa Aplicada Maker Spaces e Living Labs Inclusão, Sustentabilidade e Impacto Societal

Os resultados obtidos servirão de base para o refinamento dos elementos que comporão o framework a ser desenvolvido, bem como para subsidiar propostas de políticas e práticas institucionais voltadas à transição para a Educação 5.0 no Brasil.

Instruções ao Respondente

Para cada elemento de cada dimensão indique o seu grau de concordância, utilizando a escala do tipo Likert abaixo:

- 1- Nada importante
- 2- Pouco importante
- 3- Importante
- 4- Muito importante
- 5- Extremamente importante
- 9- Sem condições de opinar

Após cada bloco de perguntas, há um espaço para comentários qualitativos. Não existem respostas certas ou erradas; estamos interessados em sua opinião profissional.

Perfil do participante e instituição

Nome completo

Instituição

Estado

Área de atuação como professor de educação superior

Tempo de atuação na educação superior

Maior titulação

Dimensão TECNOLOGIA

Abaixo são apresentados os 13 elementos extraídos de frameworks da Educação 4.0 e baseados na revisão de literatura realizada neste estudo, para a dimensão **TECNOLOGIA**. Para cada elemento indique o grau de importância deste para o desenvolvimento e implementação da Educação 5.0.

Descrição dos 13 elementos: <https://forms.gle/83Fv644oVqj4nJLr9>

	1 – Nada importante	2 – Pouco importante	3 – Importante	4 – Muito importante	5 – Extremamente Importante	9 - Sem condições de opinar
Alfabetização em IA e Pensamento Computacional						
Ecossistemas Aprimorados por IA						
Acesso a Tecnologias de Ponta						
Realidade Aumentada e Virtual (AR/VR)						
Infraestrutura Inteligente para Aprendizagem Adaptativa e Mediadas por Tecnologia						
Analítica da Aprendizagem e Apoio de IA						
Blockchain para credenciais e segurança cibernética						
Redes de Alta Velocidade						
Tomada de Decisão Orientada por Dados						
Gamificação						
Aprendizado híbrido						
Sustentabilidade e Letramento em ODS por meio de Tecnologias Verdes e Digitais						
Formação Tecnológica Responsável e Sustentável						

Em sua análise, haveria outros elementos na dimensão Tecnologia não indicados acima que você gostaria de incluir? Em caso positivo, indique o(s) elemento(s) e o motivo da inclusão.

Dimensão COMPETÊNCIAS

Abaixo são apresentados os 10 elementos extraídos de frameworks da Educação 4.0 e baseados na revisão de literatura realizada neste estudo, para a dimensão **COMPETÊNCIAS**. Para cada elemento indique o grau de importância deste para o desenvolvimento e implementação da Educação 5.0.

Descrição dos 10 elementos: <https://forms.gle/E4fMEXti45xav8NDA>

	1 – Nada importante	2 – Pouco importante	3 – Importante	4 – Muito importante	5 – Extremamente Importante	9 - Sem condições de opinar
Pensamento Analítico e Crítico						
Colaboração com IA						
Cidadania Digital e Ética Digital Ampliada						
Resolução de Problemas Complexos						
Colaboração e Engajamento com o Setor Produtivo						
Adaptabilidade aos Mundos VUCA/BANI/RUPT						
Aprendizagem ao Longo da Vida, Autodirigida e Metacompetências						
Competências Socioemocionais						
Integração de Habilidades Humanas e Técnicas						
Competências Cognitivas e Socioemocionais para Profissionais do Século XXI						

Em sua análise, haveria outros elementos na dimensão **Competências** não indicados acima que você gostaria de incluir? Em caso positivo, indique o(s) elemento(s) e o motivo da inclusão.

Dimensão INOVAÇÃO

Abaixo são apresentados os 12 elementos extraídos de frameworks da Educação 4.0 e baseados na revisão de literatura realizada neste estudo, para a dimensão **INOVAÇÃO**. Para cada elemento indique o grau de importância deste para o desenvolvimento e implementação da Educação 5.0.

Descrição dos 12 elementos: <https://forms.gle/v8onKj6LdS5RatAf7>

	1 – Nada importante	2 – Pouco importante	3 – Importante	4 – Muito importante	5 – Extremamente importante	9 - Sem condições de opinar
Aprendizagem Personalizada e Adaptativa						
Aprendizagem Baseada em Problemas e em Cenários						
Tecnologias de Apoio à Analítica da Aprendizagem						
Laboratórios Não Tradicionais						
Biofeedback para Monitoramento do Bem-Estar Estudantil						
Ensino Reflexivo e Colaborativo						
Metodologias ativas						
Neurociência aplicada à educação						
Inovação Aberta e Colaboração com o Setor Produtivo						
IA Generativa para Cocriação e Pesquisa Aplicada						
Maker Spaces e Living Labs						
Inclusão, Sustentabilidade e Impacto Societal						

Em sua análise, haveria outros elementos na dimensão **INOVAÇÃO** não indicados acima que você gostaria de incluir? Em caso positivo, indique o(s) elemento(s) e o motivo da inclusão.

DESCRIÇÃO DAS DIMENSIONS

Technology

Descrição dos 13 elementos.

Alfabetização em IA e Pensamento Computacional

A alfabetização em Inteligência Artificial deve ser integrada aos currículos, capacitando os estudantes a compreender, utilizar e avaliar criticamente ferramentas de IA, como a Inteligência Artificial Generativa (GenAI), em contextos de aprendizagem, pesquisa e resolução de problemas.

Ecosistemas Aprimorados por IA

Integração de ferramentas de IA generativa em ambientes virtuais de aprendizagem (LMS) para potencializar a avaliação formativa, a geração de conteúdo e o suporte multilíngue. Inclui o uso da GenAI para o desenvolvimento de materiais adaptativos e processos colaborativos de co-criação.

Acesso a Tecnologias de Ponta

Aplicações em ecossistemas empresariais e produtivos incluem ferramentas como softwares de design de PCB, headsets de VR/AR, impressoras 3D e câmeras de alta definição — utilizadas para projetar, simular e criar sistemas reais. A GenAI amplia ainda mais a inclusão por meio de recursos de geração de voz/texto e capacidades multilíngues.

Realidade Aumentada e Virtual (AR/VR)

Incorporação da AR/VR para experiências imersivas de aprendizagem, como laboratórios virtuais e simulações baseadas em cenários, promovendo maior interação com sistemas complexos.

Infraestrutura Inteligente para Aprendizagem Adaptativa e Mediadas por Tecnologia

A integração de ferramentas de GenAI baseadas em nuvem com salas de aula inteligentes (IoT), análise em tempo real e Ambientes Conectados de Aprendizagem permite experiências seguras, adaptativas e interativas, conectando de forma fluida os domínios físico e digital sob governança institucional eficaz.

Analítica da Aprendizagem e Apoio de IA

Uso de sistemas analíticos e de apoio baseados em IA para personalizar trajetórias de aprendizagem, fornecendo atualizações em tempo real sobre o desempenho dos estudantes.

Blockchain para credenciais e segurança cibernética

Implementação de registros e certificações acadêmicas seguras, verificáveis e à prova de fraude.

Redes de Alta Velocidade

Discute a importância da conectividade de alta velocidade como elemento essencial para a efetividade da Educação 5.0, viabilizando experiências imersivas, colaborativas e baseadas em IA .

Tomada de Decisão Orientada por Dados

A IA generativa apoia análises preditivas para alertas precoces, acompanhamento de desempenho e otimização de recursos institucionais.

Gamificação

Aplicação de sistemas baseados em jogos para promover motivação, engajamento e aplicação prática de conceitos de engenharia e outras áreas em contextos reais.

Aprendizado híbrido

Combinação de modalidades presenciais e on-line para oferecer flexibilidade e personalização no processo educacional.

Sustentabilidade e Letramento em ODS por meio de Tecnologias Verdes e Digitais

Promovida pela integração de tecnologias verdes e digitais, enfatizando o alinhamento entre inovação tecnológica, objetivos de desenvolvimento sustentável e preocupações sociais e ambientais amplas.

Formação Tecnológica Responsável e Sustentável

Integra princípios de integridade ambiental, responsabilidade social e viabilidade econômica em todos os níveis de formação tecnológica, capacitando os aprendizes a tomarem decisões informadas e atuarem de forma responsável para um futuro justo e sustentável.

Competências

Abaixo são apresentados os 10 elementos:

Pensamento Analítico e Crítico

Ênfase no desenvolvimento de competências para avaliar criticamente os resultados gerados por sistemas de IA, mitigar a dependência excessiva de algoritmos e preservar o julgamento humano nos processos de tomada de decisão

Colaboração com IA

Aprender a trabalhar em parceria com sistemas de IA, aprimorando a produtividade e ampliando as capacidades humanas em processos colaborativos.

Cidadania Digital e Ética Digital Ampliada

Desenvolver competências em prompt engineering, detecção de vieses algorítmicos e aplicação ética e responsável das tecnologias de IA — indo além do mero “uso ético da IA” — ao abordar aspectos relacionados à privacidade, justiça e aos desafios éticos mais amplos.

Resolução de Problemas Complexos

Formação voltada à solução de problemas multifacetados e do mundo real, utilizando ferramentas baseadas em IA e alinhadas a frameworks centrados no ser humano e resilientes

Colaboração e Engajamento com o Setor Produtivo

Construção de comunidades de prática em parceria com o setor produtivo, visando o co-desenvolvimento de competências relevantes às novas demandas do mercado de trabalho e às tendências tecnológicas emergentes.

Adaptabilidade aos Mundos VUCA/BANI/RUPT

Desenvolvimento de conjuntos de competências robustos e voltados para o futuro, preparando os estudantes para atuar em contextos voláteis, incertos, complexos e ambíguos.

Aprendizagem ao Longo da Vida, Autodirigida e Metacompetências

A Inteligência Artificial Generativa (GenAI) possibilita a aprendizagem contínua — a qualquer hora e em qualquer lugar — nos contextos pessoais, profissionais e acadêmicos, promovendo a capacidade de aprender, desaprender e reaprender, ao mesmo tempo em que estimula a autonomia dos aprendizes e dos chamados citizen developers na resolução de problemas reais.

Competências Socioemocionais

Desenvolvimento de habilidades de comunicação, empatia, trabalho em equipe e gestão emocional, promovendo o crescimento pessoal e profissional dos indivíduos.

Integração de Habilidades Humanas e Técnicas

A integração entre habilidades humanas e técnicas é essencial, uma vez que o verdadeiro valor reside em sua combinação sinérgica, e não em sua separação.

Competências Cognitivas e Socioemocionais para Profissionais do Século XXI

O desenvolvimento da flexibilidade cognitiva, criatividade, resiliência e inteligência emocional é fundamental para os profissionais do século XXI, pois essas competências complementam a proficiência tecnológica e permitem que os futuros egressos prosperem em ambientes complexos e em constante transformação.

Inovação

Abaixo são apresentados os 12 elementos

Aprendizagem Personalizada e Adaptativa

Utiliza a Inteligência Artificial para recomendar cursos com base nas forças e fragilidades individuais dos estudantes, promovendo currículos flexíveis e apoiando projetos low-code/no-code integrados à GenAI que possibilitam a experimentação e a criação de trajetórias de aprendizagem personalizadas

Aprendizagem Baseada em Problemas e em Cenários

Transição para modelos de aprendizagem ativa e baseada em competências, nos quais os estudantes utilizam IA e AR/VR para resolver problemas reais. A GenAI apoia processos de sumarização, ideação e exploração de hipóteses, enquanto os citizen developers criam ferramentas práticas de IA que ampliam as experiências de aprendizagem

Tecnologias de Apoio à Analítica da Aprendizagem

A analítica da aprendizagem mediada por IA monitora o progresso dos estudantes, fornecendo informações estratégicas para otimizar métodos de ensino e aprimorar os resultados educacionais .

Laboratórios Não Tradicionais

Maker spaces, living labs e laboratórios virtuais/remotos favorecem a experimentação e a aprendizagem prática e interdisciplinar. Essa abordagem representa uma mudança dos laboratórios convencionais para ambientes virtuais e suportados por IA, que replicam padrões reais e permitem aos estudantes desenvolver ideias com aplicação prática imediata.

Biofeedback para o Bem-Estar

Aplicação de sistemas baseados em IA para o monitoramento da saúde mental e o apoio ao bem-estar dos estudantes, promovendo um ambiente de aprendizagem mais saudável e equilibrado.

Ensino Reflexivo e Colaborativo:

Estimula a reflexão crítica sobre o papel da IA na educação, promovendo a colaboração entre estudantes, docentes e o setor produtivo como motor de inovação. Nesse contexto, os citizen developers atuam como pontes entre as necessidades reais e as soluções tecnológicas institucionais.

Metodologias Ativas

Implementação de estratégias como flipped classrooms (salas de aula invertidas) e aprendizagem baseada em projetos, promovendo o protagonismo estudantil e o engajamento crítico no processo de ensino-aprendizagem.

Neurociência

Aplicação de conhecimentos da neurociência para desenhar estratégias pedagógicas que potencializem a aprendizagem, a atenção e o engajamento emocional dos estudantes.

Inovação Aberta e Colaboração com o Setor Produtivo

Implementação de iniciativas amplas de Experiential Learning e Challenge-Based Learning em parceria com o setor produtivo e organizações externas, promovendo a imersão dos estudantes em contextos autênticos e incentivando a co-criação entre academia, sociedade e empresas.

IA Generativa para Cocriação e Pesquisa Aplicada:

A Inteligência Artificial Generativa amplia as possibilidades de co-criação e pesquisa aplicada, apoiando o trabalho em equipe, o desenvolvimento de protótipos e o design de soluções dentro dos contextos educacionais.

Maker Spaces e Living Labs

Utilizam princípios de design thinking, metodologias ágeis e challenge-based learning em espaços colaborativos como living labs, promovendo a criatividade, a interdisciplinaridade e a inovação sustentável entre os estudantes.

Inclusão, Sustentabilidade e Impacto Societal

Esta dimensão compreende a inovação não apenas como tecnológica, mas também como social, pedagógica e cultural. Enfatiza o desenvolvimento de uma mentalidade inclusiva e orientada para o futuro, que una tecnologia, sustentabilidade e responsabilidade social, refletindo os novos parâmetros da indústria e da sociedade.