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Transforming Education: Integrating AI-Driven Adaptation and Multimodal Approaches for Advanced Engineering Skills

Hanan Maoz
Department of Management
Bar-Ilan University
Ramat-Gan, 5290002, Israel
Hanan.Maoz@biu.ac.il

Abstract

The research explores the transformative integration of Artificial Intelligence (AI) into technological entrepreneurship education, addressing significant gaps in traditional pedagogical methods, particularly those outlined in Bloom's Taxonomy. Despite various revisions, Bloom's framework is increasingly inadequate in meeting the dynamic and complex demands of modern educational environments. The study proposes an innovative AI-enhanced educational model that positions AI as a central element in the learning ecosystem. This model conceptualizes AI's roles as an Advisor, Mediator, and Supplementary Assistant, facilitating more personalized, efficient, and collaborative educational experiences. The research methodology includes a comprehensive literature review and an in-depth case study of a technological entrepreneurship course. The findings demonstrate that AI significantly enhances traditional methods by providing real-time feedback, automating routine tasks, and bolstering cognitive processes such as analyzing, evaluating, and creating. AI's capability to personalize learning experiences, support collaborative projects, and aid decision-making is highlighted as crucial for modernizing education in the digital age. Furthermore, the study underscores the importance of ethical considerations and robust governance in AI's deployment, advocating for a balanced integration that complements rather than replaces human cognitive processes. This research contributes to the ongoing discourse on the future of education by offering a structured, scalable framework for AI integration, with significant practical implications for educators and policymakers aiming to enhance teaching and learning processes through advanced AI technologies.

Keywords
Engineering Education, Personalized Learning, AIEd-(AI-Education), AI Literacy, GAI

1.Introduction

Transitioning from Classical Pedagogy to AI-enhanced learning in Technological Entrepreneurship Education.

The ongoing research presented in this document explores the profound shifts occurring in educational methodologies, particularly in the context of technological entrepreneurship education within academic institutions. The study situates itself at the intersection of classical pedagogical frameworks, epitomized by Bloom's Taxonomy, and the emerging field of Artificial Intelligence in Education (AIEd). This introductory chapter aims to provide an overarching narrative that connects the various themes and chapters of the research, highlighting the conceptual development of AI's role in education and its implications for teaching and learning processes.

Conceptual Foundation and Bloom's Taxonomy.

The research begins with a critical examination of Bloom's Taxonomy, first introduced in 1956, which has been a cornerstone in educational theory and practice. Bloom's Taxonomy provided a hierarchical framework categorizing educational goals into six cognitive levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. This taxonomy has been instrumental in guiding educators in the development of curricula, teaching strategies, and assessment methods, with a strong emphasis on the cognitive development of the individual learner. Over the decades, Bloom's Taxonomy has undergone significant revisions to better reflect contemporary educational needs. The 2001 revision by Anderson and Krathwohl introduced a more dynamic model, emphasizing active learning and real-world application of knowledge. More recently, with the advent of digital technologies, Bloom's Taxonomy has been further adapted to integrate digital tools and collaborative learning processes, as exemplified by Churches' 2008 Digital Taxonomy. This adaptation extended the taxonomy beyond individual cognition to embrace collaborative, technology-driven learning experiences.

The Role of AI in Education: Enhancing Bloom's Taxonomy.

As the research progresses, it delves into the transformative potential of AI within educational settings. AI's integration into Bloom's Taxonomy is presented not merely as an enhancement of the existing framework but as a revolutionary shift in how educational objectives are conceived and achieved. AI's capabilities in automating tasks, personalizing learning experiences, and providing real-time feedback are seen as key drivers in this transformation. The study explores how AI enhances various cognitive processes identified in Bloom's Taxonomy. For instance, AI's ability to store and retrieve vast amounts of information supports the "Remembering" and "Understanding" stages by providing learners with instant access to knowledge. Moreover, AI's analytical tools can assist in the "Analyzing" stage, breaking down complex information into manageable parts, while its decision-making capabilities aid in "Evaluating" and "Creating," the higher-order cognitive processes.

Case Study: Transitioning a Technological Entrepreneurship Course

One of the pivotal elements of the research is a detailed case study of a technological entrepreneurship course that has successfully implemented Bloom's Taxonomy over the past decade. This course, designed for technologists and engineers, has traditionally focused on fostering a deep understanding of entrepreneurial principles through a structured, stage-based approach. The course is structured into four stages: foundational knowledge, ideation and business model refinement, prototyping and MVP development, and market validation and investor readiness. Each stage corresponds to different levels of Bloom's Taxonomy, ensuring a scaffolded learning experience that builds from basic knowledge acquisition to the application, analysis, and evaluation of business ideas in real-world scenarios. However, the research highlights an ongoing transition within this course towards integrating AI-enhanced learning methods. The integration of AI is seen as a necessary evolution to keep pace with the demands of the digital age and the complexities of the ICT sector. AI's role in personalizing learning paths, facilitating collaborative projects, and providing real-time feedback is identified as crucial for preparing students to navigate the fast-paced and ever-changing landscape of technological entrepreneurship.

Research Methodology and Theoretical Underpinnings.

The research methodology employed in this study is predominantly conceptual, relying on an extensive literature review from the past decade to establish a theoretical framework for integrating AI into educational settings. The literature reviewed spans multiple domains, including pedagogical theory, AI in education, and technological entrepreneurship, providing a comprehensive foundation for the study's arguments. By situating AI within the broader context of complex adaptive systems, the research argues for a holistic approach to educational transformation. This approach considers the interplay between AI tools, human actors (instructors and students), and the learning environment, both physical and virtual. The study advocates for a balanced integration of AI, where technology complements rather than replaces human cognitive processes, ensuring that the educational experience remains dynamic, interactive, and deeply human-centered.

Conclusion: Towards a New Educational Paradigm.

In conclusion, this research sets out to establish a theoretical foundation for the transition from classical, teacher-centered educational methods to more modern, AI-enhanced approaches. By focusing on the field of technological entrepreneurship education, the study provides valuable insights into how AI can be leveraged to create more personalized, efficient, and collaborative learning environments. The narrative that emerges from this research is one of continuity and change—continuity in the foundational principles of Bloom's Taxonomy and change in the methods and tools used to achieve educational objectives. As AI continues to evolve, its role in education will likely expand, offering new possibilities for enhancing human learning and cognitive development in ways that were previously unimaginable. This introductory chapter outlines the structure of the research document, providing a cohesive narrative that ties together the various themes and chapters. It sets the stage for a deeper exploration of AI's impact on education and its potential to transform how we teach and learn in the digital age.

1.1 Objectives

The purpose of this research is to explore the integration of Artificial Intelligence (AI) into educational frameworks, particularly focusing on how AI enhances traditional pedagogical methods and cognitive processes within technological entrepreneurship education. The study aims to establish a theoretical foundation that addresses the evolving role of AI in education, emphasizing its potential to transform learning experiences and outcomes. In addition, the research challenge centers on the limitations of classical pedagogical frameworks, such as Bloom's Taxonomy, in addressing the needs of modern education systems, particularly in the context of technological entrepreneurship. This study seeks to bridge this gap by examining how AI can be integrated into these frameworks to create more dynamic, personalized, and effective learning environments. By doing so, the research aims to address the shortcomings of traditional methods and propose a new model for AI-enhanced education. Based on the above the research objective defines as follows:

Objective 1: Evaluate the Impact of AI on Cognitive Processes in Education.

This objective focuses on assessing how AI enhances the different cognitive stages outlined in Bloom's revised taxonomy, such as remembering, understanding, applying, analyzing, evaluating, and creating. The study will analyze the extent to which AI tools and technologies can support and enhance these cognitive processes within the context of technological entrepreneurship education. The anticipated outcome is a detailed understanding of how AI can augment cognitive processes, leading to more effective and personalized educational experiences. This understanding will contribute to developing an AI-enhanced educational framework that better addresses the needs of modern learners.

Objective 2: Develop a Theoretical Model for AI Integration in Education.

This objective aims to conceptualize a new educational model that integrates AI into existing pedagogical frameworks. The model will focus on how AI can act as an Advisor, Mediator, and Supplementary Assistant in the learning process, providing personalized guidance, facilitating collaboration, and supporting instructional strategies. The expected result is a comprehensive theoretical model that outlines the roles and functions of AI within an educational ecosystem. This model will serve as a blueprint for implementing AI in educational settings, enhancing both instructional processes and learning outcomes.

Objective 3: Analyze the Practical Implications of AI-enhanced education.

The third objective is to investigate the practical implications of implementing AI in educational environments. This includes evaluating the impact on instructional methods, student engagement, learning outcomes, and the overall educational experience. The study aims to produce practical insights into the benefits and challenges of AI integration in education, offering recommendations for educators and policymakers on how to effectively incorporate AI technologies to improve teaching and learning.

2. Literature Review

Evolution of Bloom's Taxonomy: From Cognitive to Technology-Driven Learning

The literature review outlines the evolution of educational frameworks from a focus on individual cognitive development to a more collaborative, technology-enabled, and tools-based approach. This transformation reflects how educational practices have adapted to meet the demands of an increasingly interconnected and digital world. Learning is no longer confined to the internal cognitive processes of the individual; it has become a dynamic, interactive, and collaborative experience. The integration of Artificial Intelligence (AI) in education symbolizes the culmination of this evolutionary process, offering the potential to create learning environments that are not only personalized but also deeply collaborative and technologically sophisticated. In 1956, Benjamin Bloom introduced his "Taxonomy of Educational Objectives," a hierarchical framework that categorized educational goals into six cognitive levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. Bloom's taxonomy was revolutionary for its time, providing educators with a structured model that emphasized the development of higher-order thinking skills. The focus was primarily on the individual learner's internal cognitive processes, guiding them from basic recall of facts to more complex tasks like synthesis and evaluation.

This model laid the groundwork for decades of educational practice centered on fostering cognitive development within the individual (Bloom 1956). The first major revision of this taxonomy came in 2001, when Lorin Anderson and David Krathwohl updated Bloom's original framework to better reflect contemporary educational practices. Their revision introduced a more dynamic model by shifting from static nouns to active verbs, thus emphasizing the processes involved in learning. The revised taxonomy also added a new cognitive level—creating—which replaced synthesis at the top of the hierarchy. This change signaled a shift in focus from merely understanding and analyzing information to actually using it to generate new ideas and solutions. Anderson and Krathwohl's work highlighted the importance of applying knowledge in practical contexts, thereby beginning to bridge the gap between individual cognitive development and real-world application (Anderson and Krathwohl 2001).

As digital technology began to permeate all aspects of life, including education, the need for an updated educational framework became apparent. In 2008, Andrew Churches introduced "Bloom's Digital Taxonomy," which aligned the original cognitive processes with digital tools and activities. This adaptation extended Bloom's taxonomy beyond individual cognition to embrace collaborative and technology-based learning experiences. Digital tools such as blogging, podcasting, and social networking were integrated into the higher levels of cognitive processes—creating and evaluating—reflecting the growing importance of collaboration and interaction in the digital age. Churches' adaptation of Bloom's taxonomy represented a significant shift towards integrating technology into education, enabling more interactive and collaborative learning experiences (Churches 2008).

The most recent phase in the evolution of educational frameworks is characterized by the integration of AI, which has brought about a profound transformation in how education is delivered and experienced. AI technologies are now central to automating tasks, personalizing learning experiences, and providing real-time feedback. These technologies facilitate the creation of learning environments that are highly adaptive to individual needs while also supporting collaborative efforts through intelligent tutoring systems and interactive simulations. The work of Mele et al. (2022) explores how AI enhances human learning abilities, particularly in areas requiring data analysis, decision-making, and critical thinking. Their research demonstrates that AI can significantly augment cognitive processes by providing personalized learning experiences and fostering collaborative problem-solving skills (Mele et al. 2022). In parallel, Parker and Jaeger (2016) examined the application of Bloom's taxonomy to machine learning, revealing both the strengths and limitations of AI in replicating human cognitive processes.

While AI excels at lower-order tasks such as recall and recognition, it struggles with higher-order processes like synthesis and evaluation, which require creativity and critical thinking. This research underscores the need for a balanced approach to AI integration in education, where AI tools complement human cognitive capabilities rather than replace them (Parker and Jaeger 2016). The integration of AI into education represents the culmination of the ongoing evolution from a purely individualistic cognitive focus to a more collaborative, technology-enabled, and tools-based educational framework. As educational practices continue to evolve, AI's role in facilitating dynamic, interactive, and collaborative learning experiences will likely become even more prominent, further transforming how we approach education in the digital age. This progression reflects a broader trend where learning environments are no longer static or isolated but are instead part of a complex, interconnected ecosystem that leverages technology to enhance both individual and collaborative learning outcomes.

2.1 Integrating AI in the Educational Landscape

The rapid advancements in science and technology have necessitated significant changes in educational curricula and pedagogical strategies. These transformations are not merely to keep pace with technological evolution but to establish an educational framework that aligns with political, cultural, technological, and social dimensions while meeting current and future objectives. The integration of Artificial Intelligence (AI) into education has emerged as a crucial component in this transformation, providing a dynamic and responsive system capable of adapting to the demands of the digital age (Oke and Fernandes, 2020; Sison et al. 2023; Yang, 2022). The adoption of AI in education is seen as essential for achieving a qualitative leap in educational processes worldwide, enhancing both the effectiveness and efficiency of higher education institutions (Leo et al. 2021). AI is defined as the capability of computer systems to think and act intelligently, performing complex tasks such as problem-solving, data analysis, and decision-making (Samoili et al. 2020; Buttazzo 2023). Within the context of higher education, AI has the potential to revolutionize learning environments by facilitating personalized educational experiences and supporting adaptive learning platforms that cater to individual student needs. These AI-driven systems enable a more tailored approach to education, addressing specific learning gaps and providing students with the tools necessary to succeed in increasingly complex academic settings (Yolcu et al.2023;

Drigas, Papanastasiou, and Skianis 2023). The integration of AI into higher education is driven by the potential to enhance learning outcomes through intelligent tutoring systems and interactive digital curricula, which align educational content with the unique needs and progress of each student (Fiok et al. 2021; Nguyen et al. 2022). The role of AI in higher education is multifaceted, offering numerous opportunities to improve both academic and administrative processes.

AI technologies can be applied in various domains, including knowledge representation, natural language processing, and intelligent tutoring systems, among others (Xia et al. 2023; Liu and Wang 2020). These applications streamline administrative tasks such as student assessment and feedback, enabling educators to focus more on personalized instruction and less on routine administrative duties. Additionally, AI facilitates the creation of intelligent educational content, real-time data visualization, and AI-driven tutoring systems that provide individualized support to students, making education more accessible and inclusive, particularly for those with special needs (Zawacki-Richter et al. 2019; Chan, 2023). The integration of AI into higher education thus represents a significant advancement, offering a range of tools and methodologies that enhance teaching and learning processes, ultimately contributing to a more efficient and effective educational system. In summary, AI has the potential to profoundly impact higher education by creating more responsive, personalized, and efficient learning environments. The integration of AI technologies not only enhances the quality of education but also aligns with the evolving needs of students and educators in the digital age. By leveraging AI, higher education institutions can better prepare students for the complexities of the modern world, ensuring that they are equipped with the skills and knowledge necessary for success in an increasingly technological society.

2.2 Bloom's Revised Taxonomy to include AI Enhancements

The integration of Artificial Intelligence (AI) within engineering science has been the subject of significant scholarly interest, particularly in understanding how AI can enhance human cognitive abilities. The authors explore this relationship through the lens of Bloom's revised taxonomy, which provides a structured approach to understanding the different levels of human learning and cognition. AI plays a crucial role in enhancing the cognitive process of remembering by automating the retrieval and storage of vast amounts of information. This ability to recall knowledge efficiently is particularly important in contexts where timely access to data is critical, such as in high technology-based industries. McCarthy et al. (2006) describe how AI can simulate human cognition, particularly in its capacity to recall specific facts and data from large datasets. Similarly, Huang and Rust (2018) discuss how AI supports operational efficiency by facilitating the swift retrieval of information, thereby enhancing the human capacity to remember. In addition to aiding memory, AI significantly contributes to the process of understanding by processing and interpreting large volumes of data, allowing human actors to derive meaningful insights. Perez-Vega et al. (2021) highlight AI's capacity to interpret and classify data, which supports the construction of meaning from complex information. This capability aligns with the understanding stage of Bloom's taxonomy (Bloom, 1956), where the focus is on making sense of the data presented.

AI's ability to categorize and compare information enables human actors to navigate through large datasets and extract relevant insights, thereby enhancing their understanding. AI also facilitates the application of knowledge, particularly in executing learned procedures in new and unfamiliar situations. Garry and Harwood (2019) illustrate how AI systems leverage their learned experiences to perform tasks efficiently, enabling human actors to apply knowledge in various contexts. This practical application of knowledge reflects Bloom's emphasis on the ability to use acquired skills in real-world scenarios, where AI acts as a critical tool in transferring theoretical knowledge into practice. Furthermore, AI's analytical capabilities allow it to break down complex datasets into manageable components, aiding human actors in understanding and manipulating data. Chung et al. (2016) discusses how AI analyzes large datasets to identify patterns and relationships, thereby supporting human actors in the critical task of analysis. This process aligns with Bloom's taxonomy, which emphasizes the importance of breaking down information into its constituent parts to facilitate deeper understanding and problem-solving. AI's role extends into the evaluation process, where it supports human decision-making by assess data against set criteria. Stahl et al. (2021) explore how AI aids in evaluating the effectiveness of different strategies, providing human actors with critical insights necessary for making informed judgments. This ability to critique and check the consistency of data is central to the evaluation phase in Bloom's taxonomy, where decisions are made based on rigorous analysis and comparison. Beyond analysis and evaluation, AI has the potential to contribute to the creation of new knowledge. Meyer et al. (2020) and Huang and Rust (2018) demonstrate how AI systems synthesize diverse inputs to generate innovative solutions to complex problems. This creative process, as outlined in Bloom's taxonomy, involves generating new ideas and concepts, where AI acts not just as a tool for learning but as a collaborator in the creative process, capable of producing novel outcomes from the data it processes.

2.3 Multifaceted Impact of Intelligence in Cognitive Domains

By integrating these perspectives, the authors emphasize the multifaceted role of AI in enhancing human learning abilities across different cognitive domains. Mechanical intelligence, as discussed by Huang and Rust (2021), plays a vital role in automating data retrieval and processing tasks, thereby aiding in both the remembering and understanding of information. The ability of AI to categorize and recall data in real time allows human actors to access and process information more efficiently, reducing errors and improving decision-making accuracy. Thinking intelligence, on the other hand, enhances the application, analysis, and evaluation of knowledge. AI systems support human actors by applying learned procedures to new situations, analyzing complex datasets, and making informed decisions based on systematic data processing. The works of Buhalis et al. (2019) and Stahl et al. (2021) provide examples of how AI enhances these cognitive abilities, enabling more efficient and effective decision-making processes. Feeling intelligence introduces a more nuanced interaction between AI and human cognitive processes, particularly in the realms of evaluation and creation.

Schuller (2018) discusses how AI systems with feeling intelligence are capable of empathetic understanding, responding to human emotions in ways that enhance interpersonal interactions and support the creation of emotionally informed solutions. This integration of emotional intelligence into AI's capabilities aligns with the higher-order cognitive processes of evaluation and creation in Bloom's taxonomy, where AI supports the generation of new, emotionally resonant interactions and decisions. In summary, the literature reviewed presents a comprehensive framework for understanding how AI enhances human cognitive abilities across different levels of Bloom's revised taxonomy. By automating memory, aiding understanding, facilitating the application of knowledge, supporting analysis and evaluation, and contributing to creative processes, AI emerges as a powerful tool in enhancing human learning. The authors call for further research to explore how these different types of AI intelligences can be combined and applied across various domains, beyond the context of healthcare, to fully realize AI's potential as both a learner and a learning enhancer.

Chronological Development of Bloom's Taxonomy

The following analysis aimed to examine the chronological development of Bloom's Taxonomy by comparing its original framework, the revised version, and the AI-enhanced model. It describes how each iteration has evolved to incorporate different levels of cognitive processes, the role of AI in learning, and the impact on instructional strategies, highlighting the increasing complexity and adaptability in educational approaches over time.

Table 1. Chronological Development of Bloom's Taxonomy

Principle	**Bloom's Taxonomy** (Bloom, 1956)	**Revised Bloom's Taxonomy** (Anderson et al., 2001)	**AI-Enhanced Taxonomy** (Mele et al., 2022)
Structure of Cognitive Categories	Six levels, all nouns: Knowledge, Comprehension, Application, Analysis, Synthesis, Evaluation.	Six levels, action verbs: Remembering, Understanding, Applying, Analyzing, Evaluating, Creating.	Integrates AI-driven cognitive processes into Bloom's levels: Mechanical, Thinking, and Feeling Intelligences mapped to cognitive categories.
Order of Cognitive Processes	Hierarchical, linear progression from Knowledge to Evaluation.	Hierarchical with more flexibility; Creating is the highest level.	More dynamic, with AI enhancing cognitive processes at each level; recognizes AI's role in non-linear and adaptive learning.
Highest Cognitive Process	Evaluation considered the most complex.	Creating considered the most complex.	Creating remains the most complex but is significantly enhanced by AI-driven creativity and innovation.
Role of AI in Learning	Null. Not considered.	Null. Not explicitly addressed.	Central to the model; AI enhances learning at every level by supporting data processing, decision-making, and emotional intelligence.
Incorporation of Knowledge Types	No explicit differentiation between types of knowledge.	Differentiates between Factual, Conceptual, Procedural, and Metacognitive knowledge.	AI tools are seen as facilitators across all knowledge types, enabling deeper interaction with factual, conceptual, procedural, and metacognitive knowledge.
Focus on Learning Approach	Traditional, teacher centered.	Student-centered, active learning.	AI-driven, with a focus on enhancing human learning abilities through automation, augmentation, and empathy.
Nature of Cognitive Processes	Static and distinct categories, linear progression required.	Dynamic and interconnected, allowing overlap.	Highly dynamic; AI enhances and sometimes automates cognitive processes, making learning more adaptive and personalized.
Creativity and Innovation	Synthesis is second highest, focused on combining elements.	Creating as the highest process, emphasizing original output.	AI significantly boosts creativity, enabling learners to generate new ideas and solutions more effectively.
Evaluation Process	Evaluation as a final judgment based on criteria.	Evaluation is a key process but less complex than creating.	AI aids in real-time evaluation and feedback, making the evaluation process more continuous and integrated with other cognitive processes.
Application and Transfer	Focus on applying knowledge in familiar contexts.	Emphasizes applying knowledge in varied contexts.	AI assists in applying knowledge to new and complex contexts, enhancing problem-solving and decision-making capabilities.
Metacognition	Null. Not explicitly addressed.	Recognized through Metacognitive Knowledge.	AI supports metacognitive processes by providing tools for self-assessment and reflection, helping learners monitor and adjust their learning strategies.
Assessment and Feedback	Focus on mastery of complex tasks.	More diverse, formative and summative assessments.	AI enables continuous, formative assessments with real-time feedback, allowing for more personalized learning paths.
Instructional Implications	Encourages a structured, step-by-step teaching approach.	Supports flexible, adaptive teaching strategies.	Suggests a partnership between human and AI, where AI tools enhance instructional strategies, providing adaptive learning environments and personalized instruction.

Summarizing the Transformative Power of AIEd

The introduction of AI as a core component marks a significant departure from the original Bloom's taxonomy of 1956. The 1956 framework did not account for technology or AI, focusing instead on human-centered cognitive processes with an emphasis on teacher-led instruction and traditional learning methods. However, the 2022 model integrates Artificial Intelligence (AI) into the learning process as a central element that enhances all levels of cognitive processes. This integration includes three types of AI intelligence—Mechanical, Thinking, and Feeling—that correspond to different cognitive functions, allowing for automation, augmentation, and personalization of learning, innovations that were not considered in the original taxonomy (Mele et al. 2022, 79-81; Huang and Rust 2018, 155). A key evolution in the 2022 model is the recognition of dynamic and non-linear learning pathways. While the original 1956 taxonomy is hierarchical and linear, suggesting that learners must master each cognitive level before progressing to the next, the new model acknowledges that learning is dynamic and often non-linear, especially when enhanced by AI. This approach allows learners to move fluidly between different levels of cognition with the support of AI tools. For example, AI can enable learners to jump directly into higher-order thinking, such as analysis or creation, without strictly following the linear progression prescribed by the original taxonomy (Mele et al. 2022, 82-83; Anderson and Krathwohl 2001 65).

Moreover, the 2022 model introduces personalization and adaptive learning as a core innovation. The original Bloom’s taxonomy did not explicitly account for personalization, instead assuming a one-size-fits-all approach where all learners progress through the same stages in a similar manner. In contrast, the 2022 model leverages AI to tailor learning experiences to individual needs, adapting content, pace, and complexity based on each learner's progress and preferences. This adaptive learning approach ensures that each learner engages with material in a way that is most effective for them, representing a significant advancement over the original model (Mele et al. 2022, 86; Nguyen et al. 2020, 17). The integration of metacognitive processes further distinguishes the 2022 model from its predecessor. Metacognition, or thinking about one's thinking, was not explicitly covered in Bloom's original taxonomy, which focused more on the direct acquisition and application of knowledge. The new model, however, supports metacognitive processes through AI tools that help learners monitor and reflect on their learning strategies. AI provides insights into learning behaviors, guiding learners in self-assessment and fostering a deeper understanding of how they learn best (Mele et al. 2022, 89; Greiner et al. 2021, 27). Enhanced creativity and innovation are also central to the 2022 model, which places a strong emphasis on creativity—an aspect that was not the pinnacle of cognitive achievement in Bloom's original taxonomy.

In the 1956 taxonomy, Synthesis was the second-highest level, where learners combined elements to form new structures or ideas. The 2022 model, however, uses AI to enhance creativity by enabling learners to generate novel ideas, solutions, and content more efficiently and innovatively than previously possible (Mele et al. 2022, 84; Jarrahi 2018, 577-79). Another advancement is the real-time feedback and continuous assessment integrated into the 2022 model. In the original taxonomy, Evaluation was the highest cognitive level, with assessment often being summative and occurring at the end of a learning process. The 2022 model, however, integrates AI-driven continuous assessment and real-time feedback throughout the learning process. This allows for ongoing evaluation, providing immediate feedback and enabling adjustments in learning strategies, thereby enhancing the overall learning experience (Mele et al. 2022, 85; Stahl et al. 2021, 269). Furthermore, the 2022 model incorporates emotional and social learning, addressing a broader range of human learning experiences. Bloom's original taxonomy focused primarily on cognitive processes related to intellectual tasks, with little consideration for the emotional or social aspects of learning. The 2022 model introduces Feeling Intelligence, where AI helps enhance emotional and social learning, including the ability to recognize and respond to emotions, fostering empathy, and supporting social interactions.

This inclusion acknowledges that emotional intelligence is as important as cognitive skills (Mele et al. 2022, 87; Schuller 2018, 102). Lastly, the scalability and access to knowledge offered by the 2022 model is a significant innovation compared to the 1956 taxonomy. The original framework was based on traditional methods of knowledge dissemination, where access to information was limited by the capacity of human instructors and physical resources. In contrast, the 2022 model leverages AI to scale learning experiences, providing vast access to knowledge and resources. AI's ability to process and deliver information far beyond the capabilities of a single educator makes high-quality education more accessible to a global audience, enabling personalized and comprehensive education at an unprecedented scale (Mele et al. 2022, 88; McKinsey 2020, 25). This structure follows Bloom’s original hierarchy, moving from basic knowledge and understanding (introduction of AI and dynamic learning pathways) through application (personalization), analysis (metacognitive processes), synthesis (creativity), and evaluation (real-time feedback), and finally addressing the broader implications for emotional learning and global access to knowledge.

3.Methods

Research Questions 1:

How does the taxonomic transition from Bloom's 1956 framework to the AI-enhanced model proposed by Mela in 2022 reshape the components, impact, and outcomes of educational practices, particularly in the context of cognitive development and knowledge application? This question seeks to explore the evolution of educational taxonomies from Bloom's original cognitive framework to Mela's AI-integrated model. It invites an in-depth examination of how the integration of AI alters the foundational components of the taxonomy, the resulting impact on teaching and learning processes, and the outcomes in terms of student engagement, comprehension, and knowledge application. Addressing this question requires a comprehensive review of theoretical and empirical literature to understand the implications of this taxonomic shift on modern educational practices.

Research Question 2:
What roles do AI technologies and methodologies play in enhancing learning environments—self-directed learning, peer collaboration, and instructional processes—according to the AI Education model developed in this study, and what are the theoretical and practical implications of these roles? This question aims to investigate the roles that AI technologies assume within different learning environments, as conceptualized in the AI Education model developed in this research. It calls for a thorough analysis of how AI supports self-directed learning, facilitates peer interactions, and optimizes instructional processes, along with the broader theoretical and practical implications of these roles. The question is designed to guide an extensive exploration of AI's multifaceted contributions to education, grounded in both theoretical foundations and practical applications.

Mapping Objectives to Research Questions

Objective 1: Investigates how the transition from classical to AI-enhanced educational frameworks reshapes cognitive processes and learning outcomes.
Objective 2: Explores the roles of AI in enhancing learning environments and instructional processes.
Objective 3: Examines the practical implications and challenges of integrating AI into education.
These objectives are interconnected, collectively addressing the challenge of enhancing educational frameworks through AI and generating valuable theoretical and empirical insights.

Research Methodology

The research methodology is designed to systematically align the research objectives with the corresponding research questions, ensuring a cohesive and scientifically rigorous approach to exploring AI's impact on educational frameworks. This methodology leverages integrated literature review, conceptual analysis, and in future action research scientific validation techniques to provide both theoretical insights and practical applications.
The proposed methodology, which integrates comprehensive literature reviews, conceptual framework development, and critical conceptual analysis, is strongly supported by existing scholarly research in the field of AI integration in education. Here are three advanced scholarly articles that validate the methodological considerations outlined.

Comprehensive Literature Review:
For each objective, a thorough literature review will be conducted to explore existing theories, frameworks, and empirical studies related to AI integration in education. This review will span cognitive processes, pedagogical strategies, and the practical implementation of AI tools in educational contexts. The review will identify theoretical gaps and inform the development of a conceptual framework that underpins each objective. The importance of a thorough literature review in building a conceptual framework is highlighted by Zawacki-Richter et al. (2019), who argue that "systematic reviews are essential for synthesizing knowledge and identifying gaps that future research can address, particularly in rapidly evolving fields like AI in education" (Zawacki-Richter et al. 2019). This supports the approach of conducting a comprehensive literature review to inform the development of a robust conceptual framework.

Conceptual Framework Development: Based on the literature review, a conceptual framework will be developed for each objective. These frameworks will hypothesize the relationships between AI, cognitive processes, learning environments, instructional practices, and practical outcomes. The frameworks will serve as a theoretical foundation, guiding subsequent analysis and action research. Holmes et al. (2019) emphasize the value of critical conceptual analysis in refining theoretical models, stating, "Conceptual analysis allows researchers to rigorously evaluate and refine theoretical frameworks, ensuring they are robust and applicable in diverse educational contexts" (Holmes et al. 2019). This approach aligns with the proposed methodology's focus on critical conceptual analysis and iterative model refinement.

3.1 Critical Conceptual Analysis:

Apply critical conceptual analysis to each objective's framework to examine the underlying theoretical constructs and their interrelationships. This analysis will identify potential weaknesses in the frameworks and suggest refinements to enhance their theoretical robustness. The analysis will also consider the broader implications of AI integration in education, ensuring that the frameworks are both comprehensive and adaptable.

Model Refinement through Iterative Analysis:
Iteratively refine the conceptual models based on insights gained from the analysis. This process will involve re-evaluating and adjusting the theoretical constructs to ensure that the models accurately reflect the complex dynamics of AI-enhanced educational practices. A study by Selwyn (2019) further validates the importance of iterative refinement in conceptual model development, noting that "iterative analysis and refinement of models are crucial in ensuring that theoretical constructs remain relevant and accurately reflect the dynamic nature of educational practices, especially when integrating new technologies like AI" (Selwyn 2019). This reinforces the methodology's emphasis on iterative refinement to enhance the theoretical robustness of the models.

Conceptualizing the Narrative of AI's Integration in Adaptive Education Systems

The exploration of Artificial Intelligence (AI) in service science has opened new avenues for understanding how these technologies can augment human cognitive abilities. By examining AI through the lens of Bloom's revised taxonomy, a comprehensive narrative emerges that elucidates AI's multifaceted role in enhancing various stages of human learning. This narrative not only underscores AI's capacity to support basic cognitive functions such as memory and understanding but also highlights its potential to engage in more complex processes like analysis, evaluation, and creation. Through this narrative, AI is positioned not merely as a tool for automation but as an active collaborator in the cognitive and emotional dimensions of human learning. The narrative begins with the foundational role of AI in augmenting human memory and understanding. AI's ability to efficiently retrieve and process vast amounts of data allows it to function as an external cognitive assistant, supporting human actors in recalling important information swiftly. This foundational support extends into the realm of understanding, where AI's capacity to interpret and classify data enables human users to construct meaning from complex datasets.

This capability is crucial in-service contexts where timely and accurate data interpretation can significantly impact decision-making and operational efficiency. As the narrative progresses, it delves deeper into how AI enhances higher-order cognitive functions, particularly in applying, analyzing, and evaluating knowledge. AI systems are shown to excel in applying learned procedures to new and unfamiliar situations, thus bridging the gap between theoretical knowledge and practical application. Moreover, AI's analytical capabilities allow it to break down complex problems into manageable parts, facilitating deeper understanding and more effective problem-solving. This analytical support is complemented by AI's role in evaluation, where it aids human actors in making informed judgments by critically assessing data against established criteria. The narrative presents AI as an indispensable tool in these cognitive processes, one that significantly enhances human capacity for critical thinking and decision-making. The narrative reaches its zenith in discussing AI's role in creation, the highest level of cognitive function in Bloom's taxonomy. Here, AI is portrayed as a collaborator in the creative process, capable of synthesizing diverse inputs to generate novel solutions. This creative potential is further enriched by AI's ability to engage with human emotions, a concept explored through the lens of "Feeling Intelligence."

The narrative suggests that AI's empathetic capabilities can enhance interpersonal interactions and support the creation of emotionally informed decisions, positioning AI as a partner in both the cognitive and emotional dimensions of human learning. In sum, the narrative presents a comprehensive and nuanced understanding of AI's role in enhancing human cognitive abilities across the spectrum of Bloom's taxonomy. From basic memory support to the creation of novel solutions, AI is depicted as a dynamic and integral part of the human learning process. This narrative not only reflects the current state of knowledge but also sets the stage for future research into how AI can further evolve as a collaborator in cognitive and emotional intelligence. Through this exploration, the narrative underscores the transformative potential of AI in reshaping the way humans learn, think, and create.

3.2 Conceptualizing the Paradigm Shift in AIEd

Artificial Intelligence in Education (AIEd) is an interdisciplinary field rapidly evolving to integrate AI technologies with educational practices, with the potential to revolutionize instructional design and enhance student learning (Holmes et al. 2019; Ouyang & Jiao 2021). AIEd is defined as the application of AI to improve educational practices, functioning as a transformative agent within educational systems, potentially altering traditional educational roles by acting as a new subject, mediator, or supplementary assistant (Xu et al. 2022). However, fully realizing AI's potential in education necessitates a comprehensive understanding of the complex relationships AI forms within these systems. A significant critique in the current landscape of AIEd research is the predominant focus on technological aspects, often neglecting the broader educational implications. There is a growing need to advocate for a more holistic approach that views AI as part of a complex adaptive educational system. This perspective considers the intricate and interdependent relationships between AI, human subjects (instructors and students), information, the medium of instruction, technology, and the surrounding environment (Byrne & Callaghan 2014; Kitto 2014; Von Bertalanffy, 1968). Understanding these relationships is crucial for effectively integrating AI into educational systems, ensuring that it enhances rather than diminishes the quality of education.

The literature reviewed in this chapter explores the transformative potential of AI in education, emphasizing that AI is not merely a collection of tools but a fundamental force capable of altering traditional educational roles. AI has the potential to take on roles traditionally held by instructors and students, possibly even replacing these human actors in some capacities. However, it is recognized that AI, in its current form, is limited in areas requiring self-reflection, emotional intelligence, and complex social interactions—qualities inherently human (Hwang et al. 2020; Castañeda & Selwyn 2018). Thus, while AI can offer personalized learning experiences and support instructional processes, it cannot fully replicate the nuanced and adaptive roles of human instructors and peers. A central argument presented in this chapter is the conceptualization of AI as part of a complex adaptive system within education. This view, supported by the literature, highlights the interactions between AI and other elements within the educational environment (Backlund 2000; Byrne & Callaghan 2014). Such a systemic approach allows for a more comprehensive understanding of how AI influences educational processes and outcomes, moving beyond seeing AI as an isolated technological entity or merely a collection of tools for automation and autonomy. The integration of AI into educational systems requires careful consideration of its interactions with other components to ensure that AI adoption improves educational quality (Bower 2019). This chapter also delves into the theoretical underpinnings of AI in education, particularly through the lens of complex adaptive systems theory.

This theory posits that educational systems, composed of interdependent elements like subjects, information, the medium, technology, and the environment, are sensitive to change and capable of adaptation (Backlund 2000; Kitto 2014). By examining how AI has diversified roles and influences within these systems, the chapter demonstrates how AI technologies—ranging from virtual instructors to adaptive learning platforms—are reshaping educational landscapes by adapting to evolving student needs and institutional goals (Ouyang & Jiao 2021). Moreover, the chapter highlights a paradigmatic shift from AI-directed models, where AI primarily guides the learning process, to more collaborative frameworks that position AI as a partner in learning. This shift enhances student autonomy and improves educational outcomes, signaling a transition in AI's role from automating tasks to enabling more personalized and adaptive learning experiences (Ouyang & Jiao 2021; Hwang et al. 2020). The broader implications of AI in education are also critically examined in this chapter from both technological and theoretical perspectives. Technologically, the challenges of developing AI systems that can seamlessly integrate into educational settings are discussed, particularly in terms of interaction quality and user acceptance. The chapter critiques the lack of grounding in educational and learning theories in much of the existing AI research, calling for a more comprehensive approach that incorporates pedagogical, social, and cultural dimensions (Bower 2019; Ouyang & Jiao 2021). Throughout this chapter, there is a critical reflection on AI's impact on traditional educational practices. Considerations are made regarding how AI might transform or replace human roles in education and the potential risks of over-dependence on AI technologies. The chapter argues for a balanced approach, advocating that AI should augment rather than replace human intelligence in educational contexts (Law 2019).

Conceptualizing Key Roles in AIEd: Advisor, Mediator, Assistant

Categories of AI Roles in Education: The literature review categorizes AI's roles in education into three main types: AI as an Advisor, AI as a Mediator, and AI as a Supplementary Assistant. Each role reflects a distinct way in which AI interacts with and influences the educational process. **AI as an Advisor**: In this role, AI acts as an intelligent advisor, potentially replacing traditional advisory roles such as those of instructors or peers. AI as an advisor can provide personalized learning experiences, offer real-time guidance, and simulate human-like interactions to support students. For example, AI systems can serve as tutors, offering tailored instruction and feedback to students, or as peer advisors, providing emotional and cognitive support. However, this role raises critical questions about AI's ability to fully replace human advisors, particularly in areas requiring empathy, self-reflection, and complex social interactions (Belpaeme et al. 2018; Chen et al. 2020). However, the distinguished role of AI as an Advisor raises important questions about the future of human involvement in education. While AI advisors can provide tailored learning experiences and support, they lack the nuanced understanding and empathy that human advisors bring to educational contexts (Belpaeme et al. 2018).

3.3 AI as a Mediator:

AI in this role acts as a bridge that connects different elements within the educational system. As a mediator, AI can function as a platform that supports the entire instructional process, such as through intelligent tutoring systems or interactive learning environments, or as a tool that provides specific functionalities like automated grading or personalized feedback. This role emphasizes AI's potential to enhance the efficiency and effectiveness of educational interactions. However, it also introduces concerns about over-reliance on AI, which could lead to a diminished role for human instructors and potentially reduce the overall quality of education if not managed properly (Bower 2019). However, the distinguished role of AI as a Mediator necessitates careful consideration of how AI is integrated to avoid the pitfalls of over-reliance and to ensure that technology enhances rather than diminishes educational outcomes (Bower 2019).

AI as a Supplementary Assistant:

In this role, AI indirectly influences the educational process by providing data-driven insights and predictions that assist educators and students. AI as a supplementary assistant is primarily involved in tasks like educational data mining and learning analytics, which can be used to predict student performance, identify at-risk students, and optimize learning paths. The success of this role hinges on aligning AI's analytical capabilities with the specific needs and contexts of the educational system to ensure it supports rather than detracts from educational goals (Dutt et al. 2017). However, the distinguished role of AI as a Supplementary Assistant depends on how well the AI's capabilities are aligned with the specific needs and contexts of the educational system (Dutt et al. 2017).

Conceptualizing a Model for AIEd

The AI Education Eco-System and Interaction model emphasizes the central role of AI in transforming educational environments. The primary goal of this model is to create a more personalized, efficient, and collaborative learning experience by integrating AI into various aspects of education. The model outlines two key objectives to achieve this goal. First, it aims to enhance the instructional process by positioning the AI Advisor as a guide for both instructors and students, helping in the design and delivery of educational content while supporting students in navigating their learning paths. Second, it seeks to improve communication and collaboration within the educational ecosystem by employing the AI Mediator, which facilitates interactions among instructors, students, and peers. This includes supporting collaborative learning processes and peer interactions, ensuring that the educational experience is more engaging and cohesive. Through these objectives, the AI Education Eco-System and Interaction model envisions a future where AI tools and platforms are integral in shaping a dynamic and interconnected learning environment. In summary, The model presents a holistic view of an AI-driven educational environment where AI tools and platforms play a central role in facilitating and enhancing instruction, learning, and collaboration. The AI elements are positioned to assist and mediate interactions among instructors, students, and their peers, ensuring a more personalized, efficient, and collaborative learning experience.

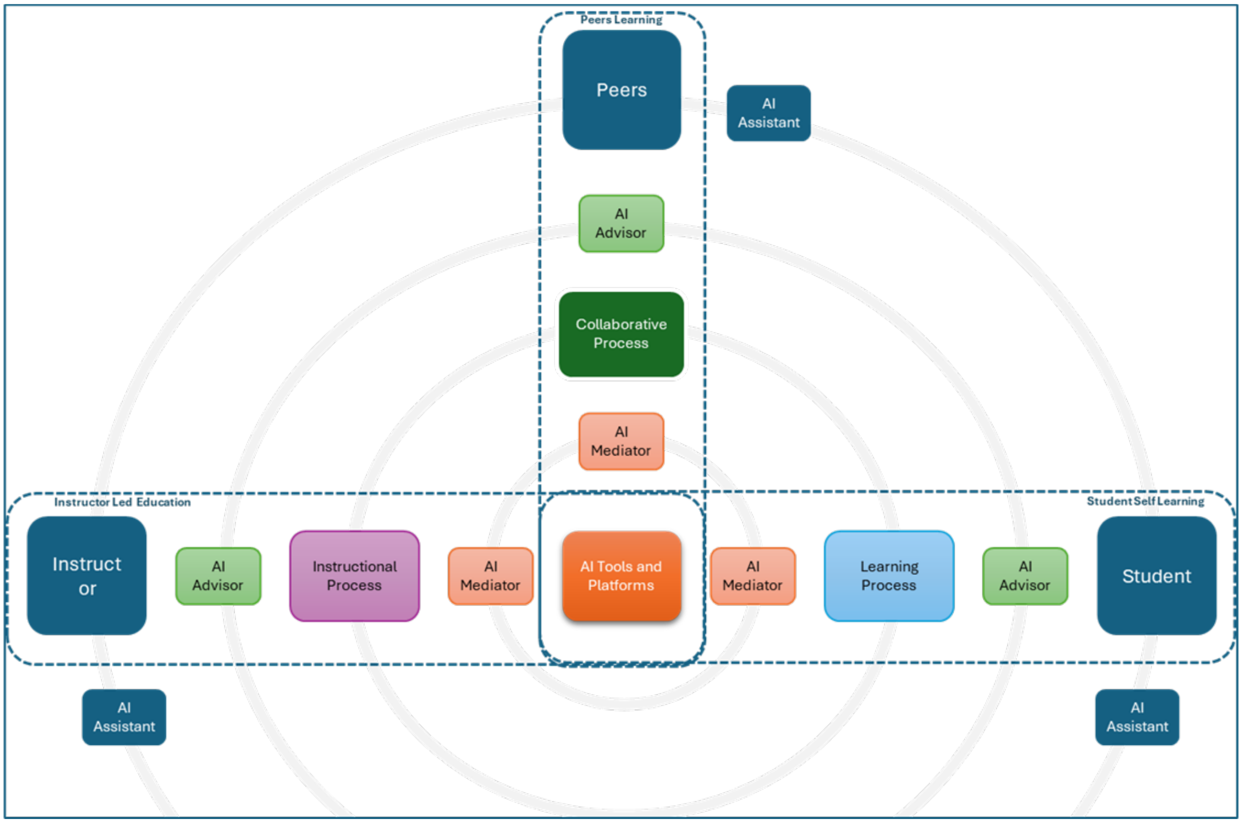

Figure 1. Conceptual AIEd Model - Layout and Objects

Model Objects:

1. Instructor: Acts as a facilitator of the instructional process.
2. Student: Engages in the learning process and interacts with AI tools and platforms.
3. Peers: Other students involved in peer learning.

AI Technologies Roles:

- AI Advisor: Provides advice and guidance both to instructors and students. It helps instructors in designing and delivering instruction and aids students in navigating their learning path.
- AI Mediator: Facilitates communication and collaboration within the educational ecosystem. It mediates between various stakeholders (instructors, students, peers) and processes (instructional and learning).
- AI Assistant: Assists both the instructor and the student in routine tasks and supports learning processes.

Learning Spaces (Processes):

- Instructional Process: This is where the instructor, aided by the AI Advisor and AI Mediator, designs and delivers educational content.
- Learning Process: The student's engagement with educational content, supported by AI tools, AI Advisors, and AI Mediators.
- Collaborative Process: A shared learning experience among students (peers), supported by the AI Mediator and AI Advisor to enhance collaboration and peer learning.

AI Tools and Platforms:

- AI Tools and Platforms: These serve as the technological infrastructure that supports the interaction between the instructor, students, and peers. AI mediators and advisors interact through these tools to enhance the educational processes.

3.4 Conceptualizing Roles of AI Technologies in the AIEd Playground

The model depicted in the image beautifully encapsulates the roles and interactions of AI within the educational ecosystem, aligning seamlessly with the academic arguments presented. Each component in the model represents the intricate ways AI is integrated into teaching and learning processes, where AI functions as an Advisor, a Mediator, and a Supplementary Assistant, supporting the various actors in the educational environment. AI as an Advisor: The model positions AI as an advisor for both instructors and students, illustrated by the roles that AI plays in guiding and enhancing the instructional and learning processes. For the Instructor-Student Learning Process, AI is shown providing personalized feedback and resources, helping instructors tailor their teaching to meet students' needs and facilitating more effective learning outcomes. The AI Advisor is crucial in the student-Self Learning Process as well, where it supports students in self-directed learning, encouraging them to take initiative and deepen their understanding, reflecting the role described by Tanaka and Matsuzoe (2012).

Similarly, in the Student and Peers Learning Process, AI acts as a peer advisor, fostering collaboration and providing emotional and cognitive support, as highlighted by Howard et al. (2017). AI as a Mediator: The central role of AI as a Mediator in the educational ecosystem is vividly depicted in the model through the various platforms and tools that connect and enhance learning processes. The Instructor-Student Learning Process benefits from AI platforms and tools that streamline content delivery, automate assessments, and manage classroom dynamics, improving efficiency and personalization, a concept supported by Bywater et al. (2019). In the Student-Self Learning Process, AI tools mediate interactions between students and their learning content, offering personalized learning paths and problem-solving support, as described by Huang and Chen (2016). Furthermore, AI’s mediation in the Student and Peers Learning Process is crucial, as it facilitates collaborative learning environments where students and peers can interact and communicate effectively, as highlighted by Lavoué et al. (2015). AI as a Supplementary Assistant: The model also illustrates AI's role as a Supplementary Assistant, providing indirect support through data-driven insights and analytics. In the Instructor-Student Learning Process,

AI tools analyze student data, predict performance, and identify at-risk students, allowing instructors to adjust their strategies, accordingly, as discussed by Hussain et al. (2018). For the Student-Self Learning Process, AI assists by recommending personalized learning paths and providing feedback, helping students navigate their educational journeys with greater ease, a role emphasized by Machado and Boyer (2021). In the Student and Peers Learning Process, AI optimizes group formation and enhances peer interactions, ensuring that collaborative efforts are more effective, as illustrated by Spoelstra et al. (2014). In summary, the model serves as a coherent and comprehensive representation of how AI is deeply integrated into the educational ecosystem. It beautifully reflects the interconnectedness of AI's roles as an Advisor, Mediator, and Supplementary Assistant, supporting instructors, students, and peers in a holistic manner. Each element of the model is harmoniously aligned with the academic arguments, demonstrating that AI not only enhances individual learning processes but also fosters a collaborative and efficient educational environment. The model is a visual testament to the transformative potential of AI in education, making the rational text come alive in a structured and aesthetically pleasing way.

3.5 Conceptualizing Learning Spaces in AIEd Playground

The Instructor-Student Learning Space (Process) is central to the model, showcasing how AI enhances the interaction between instructors and students. In this process, AI functions as an Advisor, providing personalized feedback and resources to help instructors tailor their teaching methods to meet students' needs, thereby facilitating more effective learning outcomes. As a Mediator, AI streamlines content delivery, automates assessments, and manages classroom dynamics, improving both efficiency and personalization. Additionally, AI acts as a Supplementary Assistant by analyzing student data, predicting performance, and identifying at-risk students, enabling instructors to adjust their strategies for better outcomes.

The Student-Self Learning Space (Process) emphasizes the role of AI in supporting self-directed learning. Here, AI serves as an Advisor by encouraging students to take initiative and deepen their understanding, aligning with the self-learning approaches described in academic literature. As a Mediator, AI tools guide students through personalized learning paths and offer problem-solving support, ensuring that their interactions with learning content are effective and targeted. Furthermore, AI's role as a Supplementary Assistant is evident in its ability to recommend personalized learning paths and provide feedback, helping students navigate their educational journeys with greater ease and confidence.

The Student and Peers Learning Space (Process) highlights the collaborative aspect of learning, where AI plays a significant role in facilitating peer interactions. AI functions as an Advisor by fostering collaboration and providing emotional and cognitive support, thereby enhancing the quality of peer learning experiences. In its role as a Mediator, AI facilitates a collaborative learning environment, ensuring effective communication and interaction among students and their peers. As a Supplementary Assistant, AI optimizes group formation and enhances peer interactions, making collaborative efforts more effective and aligned with educational goals. In summary, the model serves as a coherent and comprehensive representation of how AI is deeply integrated into the educational ecosystem across different learning processes. It illustrates the interconnectedness of AI's roles as an Advisor, Mediator, and Supplementary Assistant, supporting instructors, students, and peers in a holistic manner. Each element of the model is harmoniously aligned with academic arguments, demonstrating that AI not only enhances individual learning processes but also fosters a collaborative and efficient educational environment. The model is a visual testament to the transformative potential of AI in education, bringing the rational text to life in a structured and aesthetically pleasing way.

4. Analysis and Discussion

Analysis of Usability by Pivoting Learning Spaces with AI Roles

The following analysis aimed at evaluating the usability of the model by pivoting a matrix between the major components of the AIEd framework. The Y-axis represents the three learning processes (Instructional, Self, Collaborative), while the X-axis represents the three AI roles (Assistant, Advisor, Mediator). This approach provides a clear and structured view of how AI operates in various roles across different learning spaces, highlighting the interconnections and valuable functionalities as outlined in the argumentation.

Table 2. Usability by Pivoting Learning Spaces with AI Roles

Learning Process \ AI Role	**AI as Assistant**	**AI as Advisor**	**AI as Mediator**
Instructional Process	AI tools provide indirect support through data analytics, predicting student performance, identifying at-risk students, and helping instructors adjust strategies (Hussain et al. 2018).	AI offers personalized feedback and resources to instructors, helping them tailor their teaching to meet students' needs effectively (Buttussi and Chittaro 2020).	AI platforms and tools streamline content delivery, automate assessments, and manage classroom activities, making learning more efficient and personalized (Bywater et al. 2019).
Self-Learning Process	AI supports self-directed learning by recommending personalized learning paths and providing feedback, aiding students in navigating their learning journey (Machado and Boyer 2021).	AI acts as a learning advisor, guiding students in self-directed learning, encouraging them to deepen their understanding (Tanaka and Matsuzoe 2012).	AI tools mediate the student’s engagement with learning content, offering personalized paths and problem-solving support (Huang and Chen 2016).
Collaborative Process	AI assists in forming effective learning groups, optimizing peer interactions to ensure that collaborative efforts are more effective (Spoelstra et al. 2014).	AI serves as a peer advisor, facilitating collaboration, and providing cognitive and emotional support among students and peers (Howard et al. 2017).	AI platforms create collaborative learning environments, enabling effective communication and interaction among peers (Lavoué et al. 2015).

4.1 Discussion:

The above analysis aimed at evaluating the usability of the AI-driven model by pivoting a matrix between the key components of the AIEd framework. The analysis reveals that when AI is employed across different learning processes—Instructional, Self, and Collaborative—while taking on various roles as an Assistant, Advisor, or Mediator, it significantly enhances the educational experience by providing personalized feedback, optimizing peer interactions, and streamlining content delivery. These findings suggest that AI's integration into educational frameworks can lead to more tailored and efficient learning environments, which aligns with the early literature review that emphasizes the potential of AI to transform traditional educational methods (Hussain et al. 2018; Buttussi and Chittaro 2020). The implications of this on practice include the potential for AI tools to support instructors in delivering more personalized education and for students to engage more deeply in self-directed and collaborative learning. On future studies, it underscores the importance of exploring the long-term effects of AI-mediated learning on student outcomes. Finally, future research could explore how different AI roles could be optimized for specific educational contexts to maximize their impact across diverse learning environments.

Analysis of Adaptability by Pivoting Modern Taxonomy with AI Roles
The following analysis aimed at examining the adaptability of modern educational frameworks by integrating AI technologies across different roles (Assistant, Advisor, and Mediator) within the modern Bloom's taxonomy. It describes how AI can enhance creativity, provide real-time feedback, and support personalized learning by offering dynamic and non-linear pathways that align with educational goals and metacognitive processes.

Table 3. Analysis of Learning Enhancements Across Different AI Roles as Assistant, Advisor, and Mediator

AI Enhancements in Education	AI Technologies as Supplementary Assistant	AI Technologies as Advisor	AI Technologies as Mediator
AI as a Core Component	Provides data-driven support for generating innovative business ideas.	Guides refinement of ideas and business models through tailored insights.	Facilitates integration of AI tools to ensure interconnected learning processes.
Dynamic and Non-Linear Learning Pathways	Enables flexible switching between different stages of learning (e.g., ideation, analysis).	Offers adaptive guidance based on learner progress.	Coordinates learning processes to ensure smooth transitions between stages.
Enhanced Creativity and Innovation	Supports creative processes with advanced tools that offer diverse perspectives.	Provides insights and suggestions that foster creativity and innovative thinking.	Integrates creative tools and methods within the educational framework.
Real-Time Feedback and Continuous Assessment	Offers continuous analytics that track and predict performance, providing instant feedback.	Guides improvement based on real-time feedback, enhancing continuous learning.	Supports real-time interactions and feedback mechanisms.
Personalization and Adaptive Learning	Tailors learning resources to meet individual needs, optimizing learning paths.	Provides personalized guidance, adapting to each learner's needs.	Ensures personalized learning experiences align with educational goals.
Scalability and Access to Knowledge	Expands access to scalable tools and data sets, broadening learning opportunities.	Guides effective use of resources to enhance learning.	Facilitates integration of scalable resources into the learning process.
Integration of Metacognitive Processes	Helps learners reflect on their processes through insights and analytics.	Guides self-assessment and strategic thinking, fostering metacognitive skills.	Integrates reflective practices within the educational framework.

5. Discussion:

The above analysis aimed at examining the adaptability of modern educational frameworks by integrating AI technologies across different roles (Assistant, Advisor, and Mediator) within the modern Bloom's taxonomy. The analysis reveals that when AI technologies are strategically applied in these roles, they create dynamic, personalized, and scalable learning environments that significantly enhance flexibility, foster creativity, and improve learning outcomes through real-time feedback and continuous assessment. Specifically, AI as a Supplementary Assistant enables flexible and adaptable learning paths that meet individual learner needs, while AI as an Advisor provides tools and insights that encourage innovative thinking. Additionally, AI as a Mediator facilitates seamless integration of AI tools within educational frameworks, ensuring that learning processes are interconnected and transitions between learning stages are smooth.These findings suggest that AI can profoundly contribute to modern learning by expanding access to advanced educational resources, thereby making quality education more accessible and personalized. This aligns with the early literature review, which highlights the transformative potential of AI in modernizing educational practices by supporting continuous, adaptive learning and fostering metacognitive skills. The implications of this on practice include the development of new educational strategies that leverage AI to enhance learning across multiple dimensions, promoting not only knowledge acquisition but also creative and reflective thinking among students.

Table 4. Evolution from Bloom's Classical Taxonomy to New Modern Enabled by AIEd

AI Enhancements in Education	AI Technologies as Supplementary Assistant	AI Technologies as Advisor	AI Technologies as Mediator
AI as a Core Component	**Classical Bloom:** Understanding.	**Classical Bloom:** Analyzing.	**Classical Bloom:** NULL.
	Modern Taxonomy: Creating innovative ideas.	**Modern Taxonomy:** Synthesizing and refining ideas.	**Modern Taxonomy:** Integrating AI tools into learning processes.
Dynamic and Non-Linear Learning Pathways	**Classical Bloom:** NULL;	**Classical Bloom:** Applying.	**Classical Bloom:** NULL.
	Modern Taxonomy: Applying dynamic pathways.	**Modern Taxonomy:** Adapting and refining learning paths.	**Modern Taxonomy:** Coordinating flexible learning transitions.
Enhanced Creativity and Innovation	**Classical Bloom:** Creating.	**Classical Bloom:** Evaluating.	**Classical Bloom:** NULL.
	Modern Taxonomy: Innovating with AI tools.	**Modern Taxonomy:** Innovating through personalized insights.	**Modern Taxonomy:** Integrating creative methods into learning.
Real-Time Feedback and Continuous Assessment	**Classical Bloom:** Evaluating.	**Classical Bloom:** Analyzing	**Classical Bloom:** NULL.
	Modern Taxonomy: Continuous analysis and feedback.	**Modern Taxonomy:** Iterative improvement through real-time guidance.	**Modern Taxonomy:** Mediating real-time interactions and feedback.
Personalization and Adaptive Learning	**Classical Bloom:** NULL;	**Classical Bloom:** Understanding	**Classical Bloom:** NULL.
	Modern Taxonomy: Adapting learning resources.	**Modern Taxonomy:** Tailoring educational experiences.	**Modern Taxonomy:** Mediating personalized learning alignment.
Scalability and Access to Knowledge	**Classical Bloom:** Understanding.	**Classical Bloom:** NULL.	**Classical Bloom:** NULL.
	Modern Taxonomy: Expanding and applying scalable knowledge.	**Modern Taxonomy:** Strategically utilizing scalable resources.	**Modern Taxonomy:** Facilitating scalable educational integration.
Integration of Metacognitive Processes	**Classical Bloom:** Evaluating.	**Classical Bloom:** Evaluating;	**Classical Bloom:** NULL.
	Modern Taxonomy: Reflecting and self-assessing with AI.	**Modern Taxonomy:** Encouraging metacognitive growth.	**Modern Taxonomy:** Supporting metacognitive integration in learning.

On future studies, this analysis emphasizes the importance of exploring the long-term impacts of AI-integrated learning environments on student creativity, adaptability, and overall educational outcomes. Finally, future research could explore how the roles of AI—Assistant, Advisor, and Mediator—can be further optimized and tailored to meet specific educational goals, particularly in diverse and evolving learning contexts, to maximize their effectiveness in enhancing student learning experiences.This comprehensive discussion demonstrates that the matrix approach, by pivoting modern taxonomy with AI roles, serves as a robust foundation for developing innovative educational strategies that harness the capabilities of AI technologies, ultimately contributing to a more dynamic and effective learning landscape.

Analysis of the Sustained Advantage (Advantage ability) of AIEd

The following analysis aimed at examining the sustained advantage of AI in education (AIEd) by illustrating the evolution from Bloom's classical cognitive processes to those enabled by modern AI technologies. It describes how these advancements facilitate more dynamic, personalized, and reflective learning experiences, offering a clear distinction between the impacts of traditional and modern educational taxonomies on the future landscape of AIEd.

5.1.Discussion:

The above analysis aimed at examining the sustained advantage of AI in education (AIEd) by illustrating the evolution from Bloom's classical cognitive processes to those enabled by modern AI technologies. The analysis reveals that when AI is integrated into the modern educational framework, it transforms traditional learning approaches by facilitating dynamic, personalized, and reflective experiences. Specifically, AI enhances creativity, supports real-time feedback, and enables the adaptation of learning paths to meet individual needs, thereby aligning learning processes more closely with modern educational goals.

A quantitative comparison between the traditional and AI-enabled frameworks further underscores this transformation. The analysis reveals a significant presence of "NULL" entries in Bloom's classical taxonomy, particularly in areas requiring dynamic adaptability, real-time feedback, and metacognitive processes. These gaps highlight the limitations of traditional educational methods. In contrast, the modern taxonomy, enriched by AI, shows no "NULL" entries, indicating that AI effectively addresses these shortcomings by offering versatile and comprehensive enhancements across all educational dimensions.

These findings suggest that AI not only augments the cognitive processes traditionally outlined by Bloom but also introduces new dimensions of learning that are more aligned with the demands of contemporary education. This aligns with the early literature review, which anticipated that AI could revolutionize education by providing scalable, adaptive, and personalized learning environments.The implications of these findings on practice are profound, as they point towards the necessity of integrating AI tools within educational curricula to foster more innovative and effective learning strategies. On future studies, the results emphasize the need to further investigate how AI can be systematically incorporated into different educational contexts to maximize its benefits.Finally, future research could explore how the roles of AI—whether as a Supplementary Assistant, Advisor, or Mediator—can be optimized to support specific educational objectives, particularly in fostering metacognitive skills and facilitating scalable knowledge integration in diverse learning environments.

1. Research Validation

The validation process leverages the methodological approach detailed in Chapter 3.4 and is further supported by the key findings from Chapter 4.

Validation of Research Question 1

The first research question explored how the transition from Bloom's 1956 framework to the AI-enhanced model proposed by Mela in 2022 reshapes the components, impact, and outcomes of educational practices, particularly in the context of cognitive development and knowledge application. The validation process for this question is grounded in the methodology described in Chapter 3.4, which integrates a comprehensive literature review and conceptual framework development. This rigorous approach ensures that the study's analysis of the taxonomic transition is both robust and methodologically sound. The findings presented in Chapter 4 provide strong empirical support for this transition. The results demonstrate that integrating AI into educational practices enhances cognitive processes across Bloom's revised taxonomy. Specifically, AI facilitates more dynamic, personalized, and non-linear learning pathways, significantly improving cognitive development and knowledge application. These findings confirm that the AI-enhanced model indeed reshapes educational practices, making them more adaptable and effective.

Validation of Research Question 2

The second research question examined the roles AI technologies and methodologies play in enhancing learning environments—self-directed learning, peer collaboration, and instructional processes—according to the AI Education model developed in this study. The validation process here also draws on the methodological framework outlined in Chapter 3.4, which employs critical conceptual analysis to assess the AI Education model. This approach ensures that the roles of AI as Advisor, Mediator, and Supplementary Assistant are thoroughly explored and aligned with educational outcomes. Chapter 4's findings provide compelling evidence for these roles, illustrating how AI enhances learning environments through personalized guidance, improved collaboration, and optimized instructional processes. The study's results clearly show that AI significantly contributes to self-directed learning and peer collaboration, validating the theoretical and practical implications proposed in the AI Education model.

6. Conclusion

This research offers significant advancements for both the scientific community and practitioners in the field of AI in education (AIEd). For the scientific community, the study advances our understanding of AI-driven educational models by proposing a novel framework that positions AI as a critical component in advising, mediating, and supplementing educational processes. This model effectively bridges the gap between traditional educational approaches and emerging technologies, providing a structured and scalable blueprint for integrating AI into various educational contexts. Additionally, the research introduces a modern taxonomy for AI applications in education, which categorizes AI's roles and their impact on key stakeholders, particularly instructors and students. This taxonomy refines existing classifications by incorporating the latest developments in generative AI and large language models (LLMs), offering a systematic approach to understanding and evaluating the diverse applications of AI in the educational sphere.

For practitioners, the study provides practical insights into the effective implementation of AI in educational settings. The proposed AIEd model offers a clear pathway for educators and administrators to enhance teaching strategies, foster personalized learning experiences, and streamline administrative processes through the integration of AI tools. The findings are immediately applicable in classroom settings, with the potential to significantly improve the overall quality of education. Moreover, the research emphasizes the importance of addressing ethical and legal challenges in the deployment of AI, particularly for those in leadership and policy-making roles. The study highlights the need for robust governance frameworks to ensure that AI applications in education comply with legal standards and ethical norms, thereby safeguarding the interests of all stakeholders involved.

Research Contributions

This research makes a unique contribution to the field by developing a comprehensive model for AI in education. Unlike traditional models that often treat AI as a peripheral tool, this research positions AI as a central element within the educational ecosystem, serving as an advisor, mediator, and supplementary assistant. This innovative approach not only enhances the integration of AI into educational frameworks but also offers a scalable solution adaptable to different educational contexts, broadening the potential applications of AI in education. In addition, the study contributes to the development of a modern taxonomy that categorizes AI's roles and functions within education. This taxonomy is distinct in its incorporation of the latest advancements in AI, particularly generative AI and LLMs. It provides a nuanced understanding of AI's interactions with various educational stakeholders, offering a clear framework for evaluating the effectiveness of different AI applications. This contribution is vital for both researchers and practitioners navigating the complex landscape of AI in education, providing them with the tools necessary to assess and implement AI technologies effectively.

Limitations and Future Research

Despite the valuable insights provided by this research, there are notable limitations that suggest directions for future inquiry. A significant limitation lies in the study's reliance on theoretical frameworks and models without extensive empirical validation. While the proposed model and taxonomy offer substantial conceptual contributions, their practical effectiveness has yet to be thoroughly tested in real-world educational settings. Future research should focus on pilot data collection to validate these frameworks across diverse educational contexts, gathering both quantitative and qualitative data to assess their impact on educational outcomes.

Furthermore, the absence of longitudinal studies is another limitation of this research. Educational impacts often unfold over extended periods, and short-term studies may not capture the full scope of AI's influence on learning processes. To address this gap, future research should undertake longitudinal studies that track the evolution of AI-driven educational practices over time. Such studies would provide deeper insights into the sustainability and long-term effects of AI integration in education.

Finally, the rapid pace of AI technological advancement presents a challenge for continuous evaluation. As AI tools and applications evolve, it is crucial to establish mechanisms for ongoing empirical testing to ensure that the proposed model and taxonomy remain relevant. Future research should prioritize continuous evaluation, adapting the model and taxonomy in response to technological advancements. This approach will help maintain the research's relevance, ensuring that it continues to offer timely and pertinent insights for both the scientific community and practitioners in the field of AI in education.

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1.1. Tables

1.2. Figures

2. Biography:

Dr. Hanan Maoz is a senior lecturer at Bar-Ilan University, Department of Management and spent more than 15 years in the software industry at Oracle Corp. (NASDAQ: ORCL) and Lotus Development (IBM Subsidiary) in a variety of executive positions. Dr. Maoz graduated with his Ph.D. in Industrial Engineering and Management from Ben-Gurion University in Israel, before embarking on an academic career. Main academic research interests are focused on ICT Enterprise Management, Business Value Creation, Technology Investments and Entrepreneurship, Technology Portfolios, and Industrial Engineering Operations Management.