

Empowering Middle School Minds: Harnessing Artificial Intelligence for Innovative Mathematics Education

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Introduction

In the 21st century, artificial intelligence has rapidly permeated various facets of our lives, spanning mobile technology, computing, finance, agriculture, transportation, education, and commerce. Artificial intelligence operates as a personal assistant like Siri and facilitates processes in digital shopping, journalism, stock tracking, medical diagnosis, and potential crime prediction (Castro & New, 2016; Holmes et al., 2019). McCulloch and Pitts (1943) laid the foundation for artificial intelligence's mathematical expression of neural functioning with the Boolean Circuit Model of the Brain. Alan Turing's pivotal question in 1950, "Can machines think?" led to the



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development of the Turing Test to gauge artificial intelligence's human-like thinking (Turing, 1950, p.1).

Advances in neuroscience prompted researchers to transfer human learning methods to computers and robots, elucidated through comparative studies of the brain and computers, fostering a brain-based learning approach. The primary aim of artificial intelligence studies is to surpass human problem-solving capabilities, with machine learning evolving from rule-based automation to processes overcoming complexity (Dwivedi et al., 2021; Van Vaerenbergh & Pérez-Suay, 2022). Mitchell (1997) characterizes machine learning as the study of algorithms enabling computer programs to develop autonomously through experience.

The artificial intelligence landscape witnessed significant milestones such as IBM's Deep Blue defeating chess champion Garry Kasparov in 1997 and the artificial intelligence program AlphaGo triumphing over Go world champion Ke Jie. Post-2000, deep learning, artificial neural networks, and auditory and visual recognition systems experienced substantial development. Recognition processes' advancements, coupled with cloud computing and big data progress, expedited computational processes and reduced associated costs (Center for Security and Emerging Technology, 2021).

International competition in artificial intelligence, spurred by nations like China setting progress targets, has transformed existing competitive arenas and fuelled economic development (Brattberg et al., 2020; Yu & Lu, 2021). Artificial intelligence, integral to a constellation of emerging technologies, collectively constitutes the "Artificial Intelligence Revolution," impacting robotics, machine learning, cloud computing, genomics, 3D printing, quantum encryption, 5G telecommunications, and beyond (Araya & Marber, 2023; Diamandis & Kotler, 2020). Forecasts suggesting automation of half of global human tasks (Grace et al., 2018; Manyika et al., 2017) and reports of half of organizations already utilizing artificial intelligence technologies underscore the revolutionary nature of this technological wave.

Amidst this revolution, the debate shifts from whether to use artificial intelligence in education to optimizing its efficacy in educational settings. Since the 1980s, researchers have questioned technology's role in education (as explained in Trgalová, 2022). Pea (1985) defines technology's role as empowering and reorganizing mental processes, where empowerment gauges efficiency in traditional tasks, and reorganization assesses alterations in activities and mental functioning (Trgalová, 2022). Consequently, this paper critically reviews the historical context of artificial intelligence, emphasizing the need for a nuanced understanding of its role in education, especially regarding the autonomy of reasoning processes in machines.

The Evolution and Impact of Artificial Intelligence in Education

Since the 1920s, psychologists have aimed to “automate” teaching, with Pressey's work in 1920 cited as an early example of artificial intelligence in education, combining instruction and testing through teacher-guided machines (Pressey, 1950). Presently, the human-machine relationship has evolved, fostering various artificial intelligence applications in education such as personalized learning, verbal communication education systems, exploratory learning support, education data mining, and systems catering to individuals with special educational needs (Arslan, 2017; Papaspyridis & La Greca, 2023).

Research indicates that integrating artificial intelligence into the physical world holds great potential for inquiry-based learning and the development of 21st-century skills like critical thinking and collaboration (Chu et al., 2021; Yannier et al., 2023). Globally, countries have issued policies and reports to deepen artificial intelligence development and application in education, reflecting its significant impact (Luckin et al., 2016; Yu & Lu, 2021).

Anticipating a surge in artificial intelligence investment, especially in developed countries, projections suggest that artificial intelligence education spending will surpass half of the global total, reaching \$6 billion by 2025 (HolonIQ, 2019). This investment is expected to enhance productivity for both teachers and students,

offering innovative educational services and shaping a new “ecology of education” (Edwards & Magill, 2023; Moate et al., 2021).

Generative artificial intelligence tools like ChatGPT (OpenAI) and Google Bard have demonstrated their impact in education (Aydın & Karararslan, 2023; Grassini, 2023). However, despite these advancements, there is a need for comprehensive research to assess benefits and mitigate potential risks. Educational institutions are increasingly taking on administrative supporting roles, integrating artificial intelligence into learning management systems, school management, campus administration, security, precautions, and finance (Picciano, 2012; Holmes et al., 2019).

Human intelligence has its limitations, and artificial intelligence is poised to surpass these boundaries. Artificial intelligence’s ability to reason over imprecise information, analyze affective situations, and process vast amounts of data quickly positions it as a valuable decision support system, complementing human capacity (DeCanio, 2016; Yu & Lu, 2021).

As businesses and institutions actively design artificial intelligence systems for educational applications, a general framework proposed by Yu and Lu (2021) places “Intelligent Support in Learning Process” at the center, associating it with components like “Intelligent Learning Environment” and “Intelligent Teacher Assistant.” Artificial intelligence serves as an auxiliary tool for teachers, students, school management, and families in various capacities (Knapp et al., 2003; Ouyang et al., 2023).

Three key areas identified by Wang and Cheng (2022) - “Learning from artificial intelligence,” “Learning about artificial intelligence,” and “Learning with artificial intelligence” - offer a comprehensive taxonomy for developing a complementary environment in education. While “Learning from artificial intelligence” emphasizes conceptual theory taught in an environment without teachers, “Learning with artificial intelligence” focuses on using artificial intelligence as a supporting technology in learning processes. “Learning about artificial intelligence” delves into

understanding how to use artificial intelligence and its integration into the teaching process, emphasizing the importance of artificial intelligence as a tool to enhance educational practices (Kay, 2015; Tanwar et al., 2022).

Artificial Intelligence and Mathematics Education: From Algorithms to Future Expectations

Algorithms serve as the foundation of artificial intelligence systems, shaping their functionality and classification. Mathematics and mathematics education play a pivotal role in developing artificial intelligence teaching systems, contributing to numerical and programming systems underpinning machine learning, data-driven teaching, deep learning, visual recognition, and reinforcement teaching, and vice versa (Betteridge et al., 2022, Güneş & Saralar-Aras, 2023).

The historical connection between artificial intelligence and practical teaching can be traced back to Skinner's work in the 1950s with the Smart Tutoring System, marking the inception of artificial intelligence in education (National Museum of American History, 2023; Yu & Lu, 2021). Later, machine learning systems based on big data emerged, representing the third phase of artificial intelligence evolution. Recent applications like ChatGPT, with natural language processing technologies, intensify interaction with technology, showcasing the ongoing evolution of artificial intelligence in education.

Artificial intelligence systems in education can be broadly classified into three categories:

1. **Expert Systems:** Software that mimics the work of individuals with expertise in artificial intelligence algorithms (Engelmore & Feigenbaum, 1993; Krishnamoorthy & Rajeev, 2018). These systems rely on knowledge and inference, necessitating a knowledge database related to the specific field.
2. **Intelligent Instructional Systems:** Originating in the 1970s, these systems form the mainstream of intelligent teaching, providing personalized

instruction based on a teacherless one-to-one teaching model (Lesgold, 1988; Mathan & Yeung, 2015). They represent a progression from computer-aided teaching (Balacheff, 2022).

3. **Dialogue-Based Systems:** Utilizing a dialogue-based method and fuzzy logic, these systems guide students through the learning process, offering personalized teaching (Ruan et al., 2019, Pai et al., 2021). The system evaluates student responses, provides feedback, identifies misconceptions, and offers explanations for correction (Ouyang et al., 2023).

Artificial Intelligence in Mathematics Education

The historical link between mathematics and artificial intelligence has been established positively, with artificial intelligence integrated into education using a non-routine problem-solving approach based on mathematical study and expert solution design (Richard et al., 2022).

Intelligent mathematical applications transform abstract mathematical knowledge into tangible representations, aiding human perception with physical reflections of mathematical properties (Balacheff, 2022; Lagrange, 2022). Artificial intelligence and mathematics share a symbiotic relationship, both relying on logic. While mathematics provides the foundational science for algorithm-based computing infrastructure, artificial intelligence can address mathematical problems efficiently, visualizing operations and analyses interactively and dynamically.

Despite the resistance of mathematics to technological change, artificial intelligence is poised to revolutionize mathematics education by automating processes traditionally prone to human error (Saralar-Aras et al., 2023). This shift may render the term “process error” obsolete, with technology-supported mathematics education programs contributing significantly to cognitive development and a deeper understanding of the world (Webel & Otten, 2016).

A 4-category taxonomy proposed by Van Vaerenbergh and Pérez-Suay (2022) sheds light on new artificial intelligence techniques in mathematics education:

1. **Information Extractor:** Takes observations from the real world and makes mathematical inferences.
2. **Reasoning Engine:** Draws logical conclusions from axioms found in the database.
3. **Descriptive:** Transforms solutions produced by the reasoning engine into understandable forms.
4. **Data-Driven Modelling:** Forms a database of student data, allowing various analyses, modeling, and tools related to the student.

For artificial intelligence integration in geometry teaching, addressing challenges such as developing a programming interface, establishing a standard format for information exchange, and enhancing databases with powerful search mechanisms is crucial (Quaresma, 2022). Artificial intelligence must work on understanding properties like joints and edges of objects and relationships between them, indicating the complexity of human intelligence.

Looking toward the future, expectations for artificial intelligence in education include collaborative work between teachers and artificial intelligence, providing personalized and inclusive education, educational equity, and lifelong learning. Artificial intelligence is anticipated to facilitate personalized and adaptive learning, focusing on students' core competencies, overall development, spirit, and happiness, fostering human-machine integration and promoting open and lifelong learning (Yu & Lu, 2021).

Artificial Intelligence Applications in Middle School Mathematics Education: An Overview

The integration of artificial intelligence into middle school mathematics education holds significant promise, offering robust and cost-effective tutoring solutions for students, especially those in private lessons (Bloom, 1984 as cited in Araya &

Marber, 2023; Font et al., 2022; Saralar-Aras et al., 2023). The effectiveness of artificial intelligence in education lies not solely in the technology itself but in the orchestration of its use and the dynamics of feedback loops (Balacheff, 2022).

A wide array of software, including MonuMAI, Antares, and Discourse Analytics (Clarke et al., 2018; Martínez-Sevilla & Alonso, 2022), is being developed with Microsoft Partners (2023) to create interdisciplinary teaching support tools. These tools analyze group dynamics and include applications such as learning analytics for communication insights, dyslexia apps for reading comprehension improvement, and platforms like FLEXA and the Beacon digital assistant designed to enhance personalized learning experiences (Courtois, 2019; Frattini, 2023).

Artificial intelligence (AI) applications in mathematics education can be broadly categorized into AI-based computational tools, AI-based expert systems, and intelligent teaching systems. This section discusses accessible examples of these systems: Assistments, Calculus Chatbot Sofia, PhotoMath, Ramanujan Machine, and Wolfram|Alpha.

Assisments

AssistMents (2023) serves as another illustration of artificial intelligence application in the realm of mathematics education. This particular tool aids teachers in furnishing valuable feedback to students, focusing particularly on the evaluation of open-ended questions. Developed with the specific purpose of assessing open-ended queries, AssistMents contributes to enhancing students' mathematical skills (Saralar-Aras, 2021). Consequently, it facilitates a more effective development of students' mathematical thinking abilities.

Designed for students across the primary, middle, and high school levels, AssistMents operates as a tool with a specialized focus on mathematics. Notably, it is offered as a free application, reinforcing its accessibility and commitment to fostering mathematical proficiency among students. This application's emphasis on

open-ended question assessment and its complimentary availability position it as a valuable asset in promoting enhanced mathematical learning experiences for students across various educational levels.

Calculus Chatbot Sofia

Calculus Chatbot Sofia (2023) acts as an encyclopedia, offering explanatory definitions of mathematical terms and solving simple to complex math problems, interacting with computer algebra systems like Pari or Mathematica. Specifically, Calculus Chatbot Sofia, tailored for mathematics education, functions as an encyclopedia-like dictionary, providing elucidative definitions of mathematical terms. This innovative tool takes on the role of an expansive knowledge resource, offering comprehensive explanations to aid in the understanding of various mathematical concepts. Distinguished by its capacity to decipher intricate mathematical problems, Sofia excels in unraveling elementary as well as more complex mathematical equations.

In the realm of middle school education, Calculus Chatbot Sofia emerges as a resourceful companion for both students and educators. Its interactive capabilities extend beyond conventional definitions, enabling engagement with computer algebra systems like Pari or Mathematica (Saralar-Aras, 2021). This interaction empowers Sofia to tackle intricate mathematical problems, providing a versatile and adaptive solution to a spectrum of challenges. By facilitating interactions with sophisticated algebraic systems, Sofia becomes a valuable asset for mathematics students and teachers seeking effective responses to their inquiries.

Structured to cater to students across primary, middle, and high school levels, Calculus Chatbot Sofia offers its services through a subscription model. Positioned as a paid application, Sofia's accessibility is complemented by its multifaceted utility, addressing the diverse needs of students undergoing mathematical education. In essence, Sofia's capacity to explain mathematical terms, solve problems, and

interact with advanced algebraic systems underlines its significance in enhancing the learning experiences of mathematics enthusiasts at various educational stages.

PhotoMath

Photomath (2023), a mobile app utilizing OCR technology, aids students in basic math, algebra, geometry, and more. It offers step-by-step explanations, visual aids, and animated tutorials. The paid plan, Photomath Plus, provides additional features like custom visual aids and detailed explanations for textbooks.

In detail, Photomath (PM) is a mobile app downloaded by over a million teachers globally. It utilizes OCR technology for image recognition and covers a range of mathematical topics, offering step-by-step explanations and animated tutorials. PM supports learning in basic math, algebra, geometry, statistics, calculus, and verbal problems, providing a personalized learning experience for students.

PM's interface involves scanning mathematical expressions, solving problems, and learning through step-by-step explanations. The app covers various mathematical concepts, and the paid plan, PM Plus, includes additional features like custom visual aids, detailed explanations for textbooks, and animated tutorials. The app aims to enhance students' mathematical skills and comprehension.

Ramanujan Machine

The Ramanujan Machine (2023), conceived as a tool, is dedicated to advancing the computation of irrational decimal numbers linked to significant mathematical constants like π or e . It endeavours to pioneer fresh calculation methods, steering away from repetitive patterns in favour of novel sequences. In essence, this application represents a notable leap forward in computing the decimal representations of these pivotal mathematical constants.

Delving into specifics, the Ramanujan Machine distinguishes itself as an inventive mathematical computation tool. It squarely tackles the complexities of irrational decimal numbers tied to fundamental mathematical constants. The overarching goal is to foster the evolution of inventive calculation methodologies, introducing distinctive sequences in place of predictable repetitions.

Tailored for middle and high school students, this application operates on a subscription basis, underscoring its specialized and advanced role in mathematics education.

Wolfram|Alpha

Wolfram|Alpha (2023), a computational engine, provides step-by-step solutions in response to natural language or mathematical queries. Its interface supports symbolic calculations and graphical representations, making it a versatile tool for various disciplines. Different pricing plans cater to various user categories, offering features such as extended calculation times and downloadable results.

In detail, Wolfram|Alpha (W|A) is a powerful computational engine developed by Wolfram Research. It provides answers to questions across various subjects, including mathematics, science, technology, society, and daily life. W|A employs natural language understanding and a vast database, offering step-by-step solutions rather than conventional web links. Its interface supports both symbolic calculations and graphical representations, making it a versatile tool for various disciplines (Yu & Lu, 2021).

Users can input questions in natural language or mathematical format, and W|A's fast and robust infrastructure, embedded with artificial intelligence semantic analysis technology, interprets and provides answers by cross-checking terms under thousands of topics. The interface includes tabs for different math topics, allowing users to select actions and input parameters for solving problems.

W|A offers different plans, such as “Pro” and “Pro Premium,” with features like step-by-step solutions, practical problems, guided calculators, extended calculation times, file size upload limits, and improved experiences for various user categories.

Navigating the Landscape of Artificial Intelligence in Education: Recommendations, Challenges, and Future Prospects

Recommendations have been proposed to address the challenges encountered or anticipated in the integration of Artificial Intelligence into education, with the underlying goal of enhancing teaching quality (Richard et al., 2022; Yang, 2021). Initiating improvements in education to elevate academic achievements and support learning outcomes necessitates an approach centered on the needs of both students and teachers (Luan et al., 2020; Richard et al., 2022).

Artificial intelligence applications in education accumulate vast amounts of data from diverse sources and platforms. The utilization of this diverse data and the establishment of connections among them enable targeted instructional strategies. Creating environments that harmonize data from various sources and defining the requisite standards are imperative, necessitating the development of novel methodologies for these processes (Güneş & Saralar-Aras, 2023; Yu & Lu, 2021). Ethical considerations, privacy concerns, transparency, and adherence to legislative criteria for data protection are essential obligations in data sharing, requiring the establishment of long-term trust-building mechanisms between humans and machines (Flores-Vivar & García-Peñalvo, 2023; Yu & Lu, 2021).

Effective problem-solving skills in artificial intelligence demand a well-organized reasoning ability. Modelling the intricate process of knowledge creation from cognitive and developmental psychology, which involves correlating diverse data types from different disciplines and interpreting student behavioural processes, represents a complex challenge (Shinohara, 2021; Van Vaerenbergh & Pérez-Suay, 2022). The multifaceted nature of human relations, characterized by continuous,

dynamic brain activity over an extended history, makes the development of artificial intelligence's ability to extract meaning from these interactions a distant prospect.

In the context of mathematics education in Turkey, the integration of various technologies, such as computers and smart boards, faces challenges, hindering their routine incorporation as educational tools. Successful artificial intelligence operation necessitates flexibility to align with the natural course of mathematics teaching, allowing teachers to decide on its utilization (Richard et al., 2022; Saralar-Aras et al., 2023). The role of artificial intelligence in the classroom is a subject of debate, emphasizing the need for careful consideration of human rights and ethical concerns to maximize its benefits. Identifying the ethical and moral dimensions of addressing student and teacher needs through artificial intelligence requires ongoing feedback from stakeholders.

The expectation is for machines, including artificial intelligence, to adapt to humans rather than fundamentally changing human nature (see Freire et al., 2021; Mian et al., 2020). In this review, future developments in artificial intelligence are envisioned along three dimensions. Firstly, enhancing artificial intelligence's capability to analyze dimensional data, a challenging task for teachers. Secondly, creating artificial intelligence-powered virtual learning environments (metaverse) to offer real-time data reporting and personalized teaching tools, materials, and methods. Lastly, establishing Artificial intelligence paradigms that underscore processes like equality, participation, and cooperation in education, emphasizing their crucial role in maximizing the potential benefits of artificial intelligence.

Conclusion

In delving into the incorporation of artificial intelligence into education, this discussion introduces two readily accessible applications designed for middle school mathematics education, anticipating a surge in such initiatives over the past decade. Despite the ongoing assessments of developments and recommendations, a comprehensive evaluation remains imperative. Notably, artificial intelligence

distinguishes itself by mirroring human attributes closely and progressively adopting a more human-like demeanour. Although it is envisioned that artificial intelligence could potentially replace human roles across various sectors, particularly in education, it is neither feasible nor advisable, given certain human characteristics. In the context of mathematics teaching, having artificial intelligence as an assistant to support educators in tasks such as assessment, exercises, assignments, and monitoring, while offering cognitive and affective insights, proves beneficial. Artificial intelligence can serve as a personal aide during students' extracurricular learning endeavours, offering support and providing information about their families, along with presenting student profiles based on analyses. Additionally, artificial intelligence can assist school administrators with diverse matters, from security to library utilization and performance evaluations. Nevertheless, challenges may arise due to incomplete integration, nascent developmental stages, and the multifaceted nature of data collection inherent in artificial intelligence. Therefore, it is imperative to establish high standards for swift integration and meticulous data management through human-supervised continuous control mechanisms.

The incorporation of artificial intelligence holds the promise of addressing both current and future challenges. However, concerns persist as various institutions and organizations highlight potential issues in their reports, identifying risk situations. Addressing these concerns necessitates large-scale studies, regulations, and policies developed in collaboration with various stakeholders in organized education (Center for Security and Emerging Technology, 2021; Department for Education, 2023; The European Commission, 2021). Algorithm-based processing procedures in human-machine interaction and reassuring interaction processes are critical. While the overall benefits of integrating artificial intelligence into mathematics education are apparent, the acceptance of artificial intelligence as a universally embraced technology in this domain remains debatable. Only time will reveal whether artificial intelligence can establish itself in the educational landscape, creating a classroom environment conducive to increased student engagement by handling repetitive tasks and alleviating the teacher's workload.

References

- Araya, D. & Marber, P. (2023). Introduction. Araya, D. & Marber, P. (eds.). *Augmented Education in The Global Age*. Routledge, New York, NY. (pp. 1-9). <https://doi.org/10.4324/9781003230762>
- Assistments. (2023). *Assistments official website*. <https://new.assistments.org/>
- Arslan, K. (2017). Eđitimde yapay zeka ve uygulamaları [Artificial intelligence applications in education]. *Bati Anadolu Eđitim Bilimleri Dergisi [West Anatolia Education Sciences Journal]*, 11(1), 71-88.
- Aydın, Ö., & Karaarslan, E. (2023). Is chatgpt leading generative ai? what is beyond expectations?. *Academic Platform Journal of Engineering and Smart Systems*, 11(3), 118-134. <https://doi.org/10.21541/apjess.1293702>
- Balacheff, N. (2022). Foreword: AI for the learning of mathematics In. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (Eds.), *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17* (pp 9-16). Springer Nature.
- Betteridge, J., Chan, E. Y. S., Corless, R. M., Davenport, & J. H., Grant, J. (2022). Teaching programming for mathematical scientists. In P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (Eds.), *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17*. (pp 384–419) https://doi.org/10.1007/978-3-030-86909-0_12
- Brattberg, E., Rugova, V., & Csernaton, R. (2020). *Europe and AI: Leading, lagging behind, or carving its own way?* (Vol. 9). Washington, DC, USA: Carnegie endowment for international peace.
- Calculus Chatbot Sofia. (2023). *Calculus Chatbot Sofia official website*. Harvard University. <https://people.math.harvard.edu/~knill/so>

- Castro, D., & New, J. (2016). The promise of artificial intelligence. *Center for Data Innovation*, 115(10), 32-35. <https://euagenda.eu/upload/publications/untitled-53560-ea.pdf>
- Center for Security and Emerging Technology. (2021). *Artificial Intelligence standardization white paper* (2021 ed.). <https://cset.georgetown.edu/publication/artificial-intelligence-standardization-white-paper-2021-edition/>
- Chu, S. K. W., Reynolds, R. B., Tavares, N. J., Notari, M., & Lee, C. W. Y. (2021). *21st century skills development through inquiry-based learning from theory to practice*. Springer International Publishing.
- Clarke, S. N., Resnick, L. B., & Rosé, C. P. (2018). Discourse analytics for classroom learning. In D. Niemi, R. D. Pea, B. Saxberg, & R. E. Clark (Eds.). *Learning analytics in education*, (pp. 139-154).
- Courtois, J.-P. (2019). *How AI is transforming education and skills development*. <https://blogs.microsoft.com/blog/2019/10/07/how-ai-is-transforming-education-and-skills-development/>
- DeCanio, S. J. (2016). Robots and humans—complements or substitutes?. *Journal of Macroeconomics*, 49, 280-291. <https://doi.org/10.1016/j.jmacro.2016.08.003>
- Department for Education. (2023). New drive to better understand the role of AI in education. <https://www.gov.uk/government/news/new-drive-to-better-understand-the-role-of-ai-in-education>.
- Diamandis, P. H., & Kotler, S. (2020). *The future is faster than you think: How converging technologies are transforming business, industries, and our lives*. Simon & Schuster.
- Dwivedi, Y. K., Hughes, L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., & Williams, M. D. (2021). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy. *International Journal of Information Management*, 57, 101994.

- Edwards, W., & Magill, K. R. (2023). Rethinking the educational ecology in the wake of COVID: Intellectual solidarity, teacher prestige, and educational humanization. *Policy Futures in Education*, 21(2), 220-238. <https://doi.org/10.1177/14782103221101762>
- Engelmore, R. S., & Feigenbaum, E. (1993). Expert systems and artificial intelligence. *Expert Systems*, 100(2). https://technodrom.jpexs.com/domains/jpexs.com/subdom/technodrom/Y04A2Z/2007-08/Unit%204_Expert%20Systems%20and%20AI.doc
- Flores-Vivar, J. M., & García-Peñalvo, F. J. (2023). Reflections on the ethics, potential, and challenges of artificial intelligence in the framework of quality education (SDG4). *Comunicar*, 31(74), 37-47. <http://eprints.rclis.org/43878/>
- Font, L., Gagnon1, M., Leduc, N., Richard, P. R. (2022). Intelligence in QED-Tutrix: Balancing the interactions between the natural intelligence of the user and the artificial intelligence of the tutor software. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (Eds.), *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17*. Springer Nature Switzerland. (pp. 98-140) https://doi.org/10.1007/978-3-030-86909-0_3
- Fratini, F. (2023). *Created in collaboration with Microsoft, the AI-powered continuous learning Platform “FLEXA” by MIP Politecnico di Milano is an answer to an increasing need for lifelong learning Services*. Global Banking and Finance. <https://www.globalbankingandfinance.com/created-in-collaboration-with-microsoft-the-ai-powered-continuous-learning-platform-flexa-by-mip-politecnico-di-milano-is-an-answer-to-an-increasing-need-for-lifelong-learning-servi/>
- Freire, C. A., Ferreira, F. A., Carayannis, E. G., & Ferreira, J. J. (2021). Artificial intelligence and smart cities: A DEMATEL approach to adaptation challenges and initiatives. *IEEE Transactions on Engineering Management*. <https://ieeexplore.ieee.org/abstract/document/9530200>

- Grace, K., Salvatier, J., Dafoe, A., Zhang, B., & Evans, O. (2018). When will AI exceed human performance? Evidence from AI experts. *Journal of Artificial Intelligence Research*, 62, 729-754. <https://doi.org/10.1613/jair.1.11222>
- Grassini, S. (2023). Shaping the future of education: exploring the potential and consequences of AI and ChatGPT in educational settings. *Education Sciences*, 13(7), 692. <https://doi.org/10.3390/educsci13070692>
- Güneş, H., & Saralar-Aras, İ. (2023). 21. yüzyılda matematik öğretmenin sırt çantası: Yapay zeka ile web araçlarının matematik öğretiminde kullanımı [The 21st century mathematics teacher's backpack: The use of artificial intelligence and web tools in mathematics teaching]. In S. Demir (Ed.), *Kuramdan uygulamaya sınıf içi uygulamalar [In class applications from theory to practice]*, (pp. 77-106). Nobel Publications.
- Holmes, W., Bialik, M., Fadel, C. (2019). *Artificial intelligence in education: promises and implications for teaching and learning*. Boston, MA: Center for Curriculum Redesign.
- HolonIQ. (2019). 2019 *Artificial intelligence & global education report*. HolonIQ. <https://www.holoniq.com/notes/2019-artificial-intelligence-global-education-report/>
- Kay, J. (2015). Whither or wither the AI of AIED? *Seventeenth International Conference on 2015 Workshop Proceedings*, (pp. 1–10). Madrid.
- Knapp, M. S., Copland, M. A., & Talbert, J. E. (2003). *Leading for learning: Reflective tools for school and district leaders*. CTP Research Report. <https://files.eric.ed.gov/fulltext/ED482827.pdf>
- Krishnamoorthy, C. S., & Rajeev, S. (2018). *Artificial intelligence and expert systems for engineers*. CRC press. <https://ds.amu.edu.et/xmlui/bitstream/handle/123456789/4432/%28Reference%29%20Artificial%20Intelligence%20and%20Expert%20Systems%20for%20Engineers.pdf?sequence=1&isAllowed=y>

- Lagrange, J.-B. (2022). The present and future of AI in ME: Insight from empirical research and a little more. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (eds.), *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17*, (pp 421-429). Springer Nature Switzerland.
- Lesgold, A. (1988). Toward a theory of curriculum for use in designing intelligent instructional systems. In *Learning issues for intelligent tutoring systems* (pp. 114-137). New York, NY: Springer US.
- Luan, H., Geczy, P., Lai, H., Gobert, J., Yang, S. J., Ogata, H., & Tsai, C. C. (2020). Challenges and future directions of big data and artificial intelligence in education. *Frontiers in Psychology*, 11, 580820. <https://doi.org/10.3389/fpsyg.2020.580820>
- Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). Intelligence Unleashed: An argument for AI in education. Open Research Online. <http://oro.open.ac.uk/50104/1/Luckin%20et%20al.%20-%202016%20-%20Intelligence%20Unleashed.%20An%20argument%20for%20AI%20in%20Educ.pdf>
- Manyika, J., Lund, S., Chui, M., Bughin, J., Woetzel, J., Batra, P., Ko, R., Sanghvi, S. (2017). Jobs lost, jobs gained: Workforce transitions in a time of automation. McKinsey Global Institute. <https://www.mckinsey.com/~media/mckinsey/industries/public%20and%20social%20sector/our%20insights/what%20the%20ofuture%20of%20work%20will%20mean%20for%20jobs%20skills%20and%20wages/mgi-jobs-lost-jobs-gained-executive-summary-december-6-2017.pdf>
- Martínez-Sevilla, A., & Alonso, S. (2022). AI and mathematics interaction for a new learning paradigm on monumental heritage. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (eds.), *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17*. Springer Nature Switzerland. (pp. 183-224) https://doi.org/10.1007/978-3-030-86909-0_6.

- Mathan, S., & Yeung, N. (2015). Extending the diagnostic capabilities of artificial intelligence-based instructional systems. *AI Magazine*, 36(4), 51-60. <https://doi.org/10.1609/aimag.v36i4.2616>
- McCulloch, W. S., & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *The Bulletin of Mathematical Biophysics*, 5, 115-133. <https://doi.org/10.1007/BF02478259>
- Mian, S. H., Salah, B., Ameen, W., Moiduddin, K., & Alkhalefah, H. (2020). Adapting universities for sustainability education in industry 4.0: Channel of challenges and opportunities. *Sustainability*, 12(15), 6100. <https://doi.org/10.3390/su12156100>
- Microsoft Partners. (2023). What is Azure immersive reader? Microsoft Docs. <https://docs.microsoft.com/en-us/azure/applied-ai-services/immersive-reader/overview>
- Mitchell, T. M. (1997). Machine learning. McGraw-Hill. <https://doc.lagout.org/science/Artificial%20Intelligence/Machine%20learning/Machine%20Learning%20-%20Tom%20Mitchell.pdf>.
- Moate, J., Lempel, L., Palojärvi, A., & Kangasvieri, T. (2021). Teacher development through language-related innovation in a decentralised educational system. *Professional Development in Education*, 1-16.
- National Museum of American History. (2023). *Skinner teaching machine*. https://americanhistory.si.edu/collections/search/object/nmah_690062.
- Ouyang, F., Jiao, P., Alavi, A. H., McLaren, B. M. (2023). Artificial intelligence in STEM education: Current developments and future considerations. F. Ouyang, P. Jiao, B. M. McLaren, A. H. Alavi (eds.). *Artificial Intelligence in STEM Education: The Paradigmatic Shifts in Research, Education, and Technology*. CRC Press. <https://doi.org/10.1201/9781003181187>
- Pai, K. C., Kuo, B. C., Liao, C. H., & Liu, Y. M. (2021). An application of Chinese dialogue-based intelligent tutoring system in remedial instruction for

- mathematics learning. *Educational Psychology*, 41(2), 137-152.
<https://doi.org/10.1080/01443410.2020.1731427>
- Papaspyridis, A., & La Greca, J. (2023). AI and education: Will the promise be fulfilled? Araya, D. & Marber, P. (eds.). *Augmented Education in The Global Age*. Routledge, New York, NY. (pp. 119-136)
<https://doi.org/10.4324/9781003230762>
- Pea, R. D. (1985). Beyond amplification: Using the computer to reorganise mental functioning. *Educational Psychologist*, 20(4), 167–182.
- Photomath. (2023). *Get math, get Photomath: Photomath official website*.
<https://photomath.com/en>
- Picciano, A. G. (2012). The evolution of big data and learning analytics in American higher education. *Journal of Asynchronous Learning Networks*, 16(3), 9-20.
<https://eric.ed.gov/?id=EJ982669>
- Pressey, S. L. (1950). Development and appraisal of devices providing immediate automatic scoring of objective tests and concomitant self-instruction. *The Journal of Psychology*, 29(2), 417–447.
- Quaresma, P. (2022). Evolution of automated deduction and dynamic constructions in geometry. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (eds.), *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17*. Springer Nature Switzerland. (pp 38–66)
https://doi.org/10.1007/978-3-030-86909-0_1
- Ramanujan Machine. (2023). *Ramanujan machine official website*.
<http://www.ramanujanmachine.com>
- Richard, P. R., Vélez, M. P., Van Vaerenbergh, S. (2022). General introduction. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (eds.). *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17*. (pp. 17-23)

- Ruan, S., Jiang, L., Xu, J., Tham, B. J. K., Qiu, Z., Zhu, Y., & Landay, J. A. (2019, May). Quizbot: A dialogue-based adaptive learning system for factual knowledge. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (pp. 1-13). <https://doi.org/10.1145/3290605.3300587>
- Saralar-Aras, İ., Erkol, E. D., & Akan, R. (2023). Matematik öğretiminde yapay zekâ eğitim uygulamaları [Artificial intelligence education practices in mathematics teaching]. In İ. Saralar-Aras (Ed.) *Yapay zekanın matematiği: Teori ve uygulama [Mathematics of artificial intelligence: Theory and practice]*, (pp. 49-72). Nobel Publications.
- Saralar-Aras, İ. (2021, Haziran). Matematik derslerinde yapay zekâ uygulamaları [Artificial intelligence applications in mathematics lessons]. *1. Ulusal Eğitimde Yapay Zekâ Uygulamaları Kongresi [1st Turkish National Conference of Artificial Intelligence Applications in Education]*. Çevrimiçi & Harran Üniversitesi, Şanlıurfa, Türkiye: EYZ.
- Shinohara, K. (2021). Understanding the impact of artificial intelligence on skills development. UNESCO-UNEVOC International Centre for Technical and Vocational Education and Training. https://unevoc.unesco.org/pub/understanding_the_impact_of_ai_on_skills_development.pdf.
- Tanwar, S., Badotra, S., & Rana, A. (Eds.). (2022). *Machine learning, blockchain, and cyber security in smart environments: Application and Challenges*. CRC Press.
- The European Commission. (2021). Regulation of the European Parliament and of the Council. <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021PC0206&from=EN>.
- Trgalová, J. (2022). Digital technology and its various uses from the instrumental perspective: The case of dynamic geometry. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (Eds.). *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era* 17. https://doi.org/10.1007/978-3-030-86909-0_18.

- Turing, A. (1950). Computing machinery and intelligence. *Mind*, 49(236), 433–460.
- Van Vaerenbergh, S., & Pérez-Suay, A. (2022). A Classification of artificial intelligence systems for mathematics education. P. R. Richard, M. P. Vélez and S. Van Vaerenbergh (eds.), *Mathematics Education in the Age of Artificial Intelligence, Mathematics Education in the Digital Era 17*. Springer Nature Switzerland. (pp. 158-182) https://doi.org/10.1007/978-3-030-86909-0_5.
- Wang, T., & Cheng, E. C. (2022). Towards a tripartite research agenda: A scoping review of artificial intelligence in education research. In E. Cheng, R. Koul, T. Wang, & X. Yu (Eds.), *Artificial intelligence in education: Emerging technologies, models and applications*. Lecture Notes on Data Engineering and Communications Technologies, 104, 3–24. Springer. https://doi.org/10.1007/978-981-16-7527-0_1.
- Webel, C. & Otten, S. (2016). Teaching in a world with PhotoMath. *The Mathematics Teacher*, 109(5), 368–373. <https://doi.org/10.5951/mathteacher.109.5.0368>.
- Wolfram|Alpha. (2023). *Wolfram|Alpha official website*. <https://www.wolframalpha.com/>
- Yang, S. J. (2021). Guest editorial: Precision education-A new challenge for AI in education. *Educational Technology & Society*, 24(1), 105-108.
- Yannier, N., Hudson, S. E., Koedinger, K. R. (2023). *Intelligent science stations bring AI tutoring into the physical world*. F. Ouyang, P. Jiao, B. M. McLaren, A. H. Alavi (eds.). *Artificial Intelligence in STEM Education: The Paradigmatic Shifts in Research, Education, and Technology*. CRC Press. <https://doi.org/10.1201/9781003181187>
- Yu, S. & Lu, Y. (2021). An Introduction to artificial intelligence in education. Springer. <https://doi.org/10.1007/978-981-16-2770-5>.

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