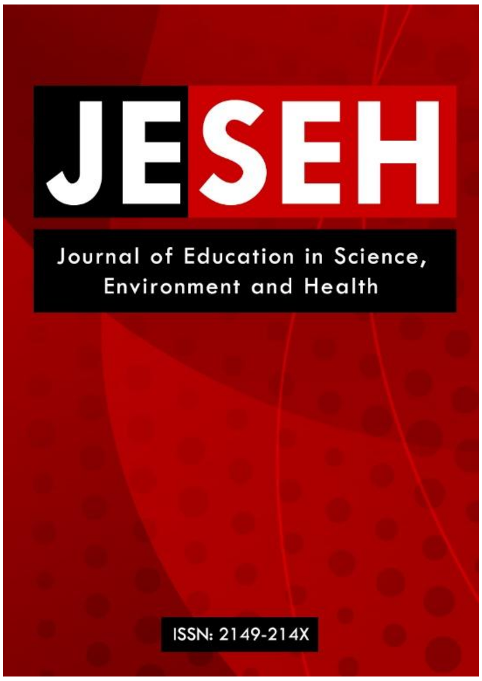

ISSN: 2149-214X

Journal of Education in Science, Environment and Health

www.jeseh.net

The Heart and Art of Robotics: From AI to Artificial Emotional Intelligence in STEM Education

Christopher Dignam, Candace M. Smith, Amy L. Kelly
Governors State University

To cite this article:

Dignam, C., Smith, C. M., & Kelly, A. L. (2025). The heart and art of robotics: From AI to artificial emotional intelligence in STEM education. *Journal of Education in Science, Environment and Health (JESEH), 11*(2), 151-169. https://doi.org/ 10.55549/jeseh.813

JESEH
Journal of Education in Science, Environment and Health
Volume 11, Issue 2, 2025
https://doi.org/10.55549/jeseh.813

The Heart and Art of Robotics: From AI to Artificial Emotional Intelligence in STEM Education

Christopher Dignam, Candace M. Smith, Amy L. Kelly

Article Info

Article History

Published:
01 April 2025

Received:
13 October 2024

Accepted:
17 March 2025

Keywords

Artificial intelligence,
Artificial emotional intelligence,
Robotics,
STEM,
STEAM

Abstract

The evolution of artificial intelligence (AI) and robotics in education has transitioned from automation toward emotionally responsive learning systems through artificial emotional intelligence (AEI). While AI-driven robotics has enhanced instructional automation, AEI introduces an affective dimension by recognizing and responding to human emotions. This study examines the role of AEI-powered robotics in fostering student engagement, cognitive development, and social-emotional learning (SEL) across early childhood, K-12, and higher education. Constructivist and experiential learning theories provide a foundation for integrating emotionally intelligent robotics into interdisciplinary and transdisciplinary STEAM education. Findings indicate that AEI enhances motivation, problem-solving, and collaboration by creating adaptive learning environments that respond to student affective states. However, challenges such as data privacy, inaccuracies in emotion recognition, and access to robotics must be addressed to ensure ethical implementation. The study advocates for further interdisciplinary research, professional growth, and infrastructure investment to optimize AEI-powered robotics in education. The study also emphasizes prioritizing emotionally intelligent interactions for AEI-driven robotics that represents a shift toward human-centered, AI applications for supporting personalized learning and holistic student development. Future directions include refining affective computing models and fostering ethical AI and AEI frameworks to ensure responsible and effective implementation in early childhood through higher educational settings.

Introduction

The rapid evolution of artificial intelligence (AI) and robotics has introduced new possibilities for education and learning design. While AI-powered tools provide automated support for instruction and assessment, artificial emotional intelligence (AEI) has emerged as a promising development that integrates affective and social dimensions into intelligent learning systems (Salas-Pilco, 2020). Robotics, particularly in educational settings, is increasingly utilized to foster cognitive, social-emotional, and problem-solving skills (Uslu et al., 2023). As robotics in education progresses from pre-programmed automation toward adaptive and emotionally responsive interactions, educators must critically evaluate its role in supporting student engagement, motivation, and personalized learning experiences.

Educational robotics has been widely studied as a tool that enhances STEM (science, technology, engineering, and mathematics) learning and fosters collaborative, inquiry-based approaches (Miglino et al., 2021). Constructivist perspectives emphasize that students benefit from hands-on learning with robotics, allowing them to experiment with programming, engineering, and problem-solving in real-world contexts (Zhu & Atompag, 2023). Additionally, robotics is not only confined to cognitive development but has also shown promise in supporting social-emotional learning (SEL) by enabling interactions that encourage communication, teamwork, and emotional regulation (Salas-Pilco, 2020; Uslu et al., 2023). However, while AI-driven robotics enhances computational thinking and self-efficacy, AEI-based robotics introduces an additional layer of engagement. Artificial emotional intelligence in robots provides AI that recognizes, interprets, and responds to human emotions, potentially reshaping educational experiences.

The shift from AI to AEI in education presents both opportunities and challenges. AI-driven robotics has been effective in automation, adaptive learning, and tutoring systems, yet it often lacks the affective and social elements that are integral to human learning (Salas-Pilco, 2020). Artificial emotional intelligence, by contrast, seeks to bridge this gap by developing emotionally intelligent robotic interactions that respond to students' needs in a more human-like manner.

In this study, the authors posit the potential for AEI-powered robotics to foster greater motivation, deeper learning engagement, and more personalized educational interactions (Salas-Pilco, 2020; Uslu et al., 2023). While AI-driven systems have demonstrated effectiveness in automating instructional processes and adapting to students' cognitive needs, the shift toward AEI introduces the possibility of emotionally attuned learning experiences that extend beyond mere content delivery. Artificial Emotional Intelligence-powered robotics possesses the potential to enhance student-teacher interactions by recognizing emotional cues, adjusting responses accordingly, and promoting a more responsive, human-like engagement with learners.

As educational institutions consider integrating AI and AEI-driven robotics into classrooms, it is essential to explore their pedagogical implications, including their capacity to support constructivism, inquiry-driven, and socially interactive learning environments (Atompag & Zhu, 2023). To address these considerations, this study examines the evolving role of AEI in education, highlighting its impact on student motivation, collaboration, and individualized learning pathways. The authors' study synthesizes current research and discusses potential applications to provide a foundational framework for integrating AEI in future educational settings while identifying emerging challenges and opportunities for educators and policymakers.

Theoretical Background

History of Artificial Intelligence in Robotics

The development of AI can be traced back to the mid-20th century when Alan Turing introduced the concept of machines that could simulate human thought (Cebollada et al., 2021). Early AI models were centered on rule-based systems, which relied on predefined logical structures to process information. However, as computational power advanced, AI evolved into machine learning (ML), where algorithms could learn from data and improve performance over time. In this context, algorithms refer to a set of mathematical rules and computational procedures that enable machines to analyze patterns, make predictions, and adjust their output based on new data.

A subset of ML, known as deep learning (DL), further enhanced AI's capabilities by utilizing artificial neural networks to recognize patterns, classify data, and performing complex tasks such as image recognition, natural language processing, and autonomous decision-making (Soori et al., 2023). Neural network advancements have significantly influenced robotics, allowing machines to adapt to changing environments, learn from experience, and perform tasks once thought to require human intelligence (Ren et al., 2023).

Machine Learning and DL are central in robotics, particularly in autonomous navigation, object detection, and human-robot collaboration. Machine learning enables robots to refine their responses based on past interactions, while DL enhances their ability to process large volumes of visual and sensor data (Cebollada et al., 2021). These technologies have revolutionized robotic perception and decision-making, enabling robots to navigate complex environments, recognize objects accurately, and adapt to unforeseen circumstances. Their applications extend across multiple domains, from robot-assisted surgeries that require precision and adaptability to industrial automation, where predictive analytics optimize production efficiency. AI-driven robotics supports personalized learning experiences in education by tailoring instructional content to students' needs and fostering engagement through interactive and adaptive systems (Zeng et al., 2020).

The Path toward Cognitive Intelligence

Artificial Intelligence-driven robotics has led to the emergence of cognitive intelligence, allowing machines to interpret human emotions, adjust their interactions accordingly, and assist in decision-making (Ren et al., 2023). Unlike traditional AI, which focuses primarily on computational efficiency and automation, cognitive intelligence seeks to bridge the gap between technical precision and human-like responsiveness. The ability to recognize and respond to emotional cues enhances the potential for robots to serve as companions in healthcare, tutors in classrooms, and collaborators in workspaces, offering a more intuitive and human-centered approach to AI implementation. The increasing sophistication of AI-powered robotics raises important considerations for educators and policymakers, as integrating these systems into learning environments requires a balance between automation and human interaction (Soori et al., 2023). Ensuring that AI remains an enhancement rather than a replacement for human educators will be critical in fostering effective and ethical applications in future classrooms.

As AI technology advances, researchers focus on AEI with an aim to equip robots with social and emotional awareness to enhance collaborative learning and student engagement. Unlike traditional AI, which prioritizes efficiency and task execution, AEI seeks to create more human-like interactions by recognizing and responding to students' affective states (Cebollada et al., 2021). The shift from AI to AEI represents a fundamental transformation in how AI-driven robotics is applied in education, moving from purely algorithmic approaches to emotionally responsive and adaptive learning systems (Figure 1). Understanding the historical trajectory of AI, from its early computational roots to machine learning, deep learning, and now AEI, provides a foundation for exploring its pedagogical implications and the future of emotionally intelligent robotics in education (Ren et al., 2023; Soori et al., 2023).

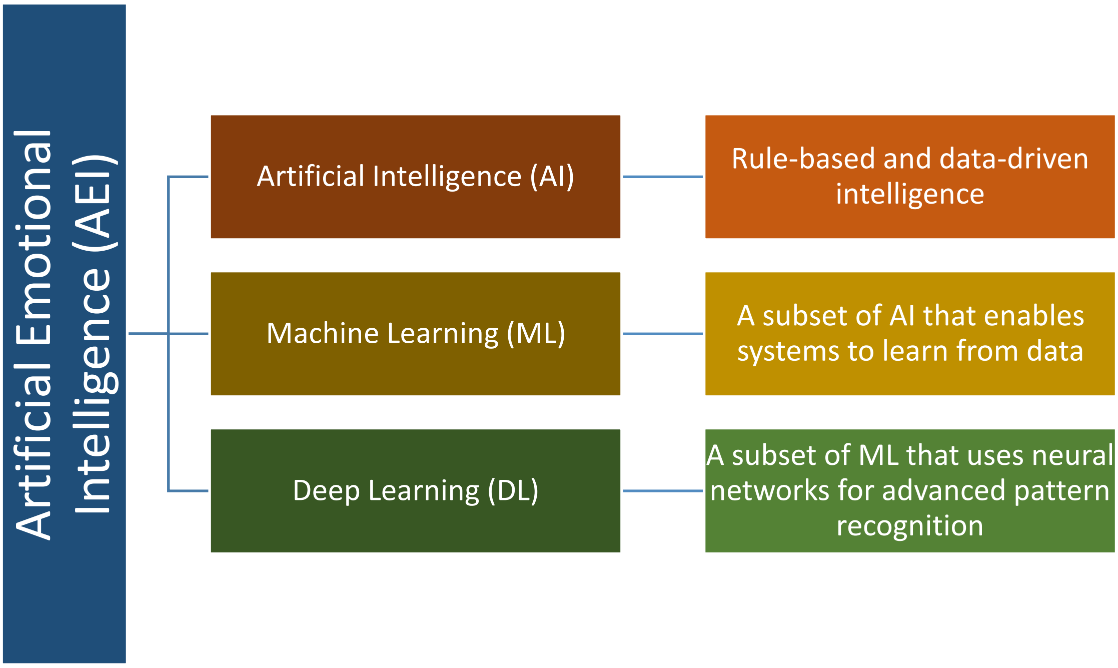

Figure 1. Emotion recognition, interpretation, and responsive interaction of AEI

History of Robotics Automation to Intelligence

The origins of robotics can be traced back to the early Industrial Revolutions, which fundamentally transformed manufacturing and technological progress. The First Industrial Revolution (IR 1.0) introduced mechanical systems driven by steam power, establishing the foundation for automation in industry (Groumpos, 2021). The Second Industrial Revolution (IR 2.0) saw the rise of electrical power, leading to the development of assembly lines and electrically operated machinery, increasing efficiency and precision.

The Third Industrial Revolution (IR 3.0), often referred to as the Digital Revolution, introduced computers and microprocessors, enabling automated production systems and early forms of AI-driven robotics (Elayyan, 2021; Ribeiro et al., 2021). The Fourth Industrial Revolution (IR 4.0), also known as Industry 4.0, expanded robotics through AI, ML, DL, and the Internet of Things (IoT), creating autonomous systems capable of learning, adapting, and interacting with their environment (Jafari et al., 2022; Mhlanga, 2022; Rotatori et al., 2021).

More recently, the Fifth Industrial Revolution (IR 5.0) has emerged as a human-centric evolution of Industry 4.0, emphasizing collaboration between humans and intelligent systems (Jafari et al., 2022; Noble et al., 2022). Unlike IR 4.0, which focuses on smart automation, IR 5.0 highlights AI and robotics designed for sustainability, resilience, and ethical decision-making in various fields, including education. The shift from Industry 4.0 to Industry 5.0 represents a transition toward emotionally intelligent robotics, ensuring AI systems enhance human capabilities rather than replace them (Tinmaz, 2020).

Robotic Interactions for a Human Touch

The evolution of robotics has led to significant advancements in cognitive robotics. Unlike traditional automation, which relies on pre-programmed commands, cognitive robots can perceive, reason, and make autonomous decisions (Levesque & Lakemeyer, 2010). The transition, facilitated by AI and neural networks, has expanded robotics beyond industrial applications, integrating them into healthcare, education, and service industries (Matthews et al., 2021).

A key development in robotics has been the rise of humanoid robots, which prioritize social interaction alongside mechanical efficiency. Early humanoid systems, such as ASIMO by Honda, focused on bipedal movement and dexterity, while modern AI-powered robots integrate speech recognition, facial expressions, and contextual decision-making (Kajita et al., 2014). Advancements in robotics, particularly through AEI, are paving the way for emotion-responsive systems that can engage with humans in more natural and adaptive ways.

However, the increasing presence of AI-driven robotics also raises philosophical and ethical concerns, particularly regarding job displacement, data privacy, and ethical decision-making in autonomous systems (Ribeiro et al., 2021). As AEI-driven robotics becomes more prevalent in education and social domains, researchers must ensure that these systems support human learning and development rather than replace human agency. A deeper historical understanding of robotics, from mechanical automation to cognitive and emotionally intelligent systems, is essential for addressing AEI's role in education and beyond (Table 1).

Table 1. Industrial revolutions and robotics pathway to AEI

Industrial Revolution	**Key Technologies**	**Impact on Robotics**	**Pathway to AI & AEI**
First IR (1760-1840)	Steam engines, mechanization	Early mechanical automation	No AI; focus on machinery replacing manual labor
Second IR (1870-1914)	Electrical power, mass production	Introduction of electromechanical systems	Automation advances but no AI integration
Third IR (1950s-Present)	Computers, microprocessors, digital systems	Robotics emerge for industrial automation	Basic AI (rule-based), early ML applications
Fourth IR (2011-Present)	AI, ML, DL, IoT, Cognitive Robotics	Adaptive robots, autonomous systems	AEI-driven humanoid robots, emotion-responsive AI
Fifth IR (Emerging)	Human-centric AI, AI ethics, sustainable automation	Human-machine collaboration, socially responsible robotics	Emotion-aware AI, AI-driven ethics, sustainable tech

Artificial Emotional Intelligence

Enhancing Human-Machine Interaction

Artificial Emotional Intelligence represents a significant advancement in the field of AI by incorporating the ability to recognize, interpret, and respond to human emotions. Unlike traditional AI, which primarily focuses on logic-driven decision-making, AEI seeks to simulate emotional intelligence by analyzing facial expressions, speech patterns, physiological responses, and contextual cues (Kumar & Martin, 2023). Emotional recognition is facilitated through a combination of ML and DL models, which process data from various sources to detect emotional states with increasing accuracy. Facial emotion recognition, for example, leverages computer vision and neural networks to classify emotions such as happiness, anger, sadness, and surprise (Narimisaei et al., 2024). The integration of speech emotion detection and multimodal data fusion enhances human-machine interactions, making technology more intuitive and responsive in education, healthcare, and service industries.

The development of AEI has the potential to bridge the gap between human cognition and AI, fostering more natural, engaging, and empathetic interactions. Emotion recognition technologies are already being implemented in customer service automation, mental health monitoring, and personalized learning platforms (Kambur, 2021). Within educational settings, AEI plays a transformative role by adapting instructional delivery based on students' affective states, thereby improving engagement, motivation, and learning outcomes. Artificial intelligence-powered tutors equipped with AEI can detect frustration, confusion, or boredom and adjust lesson pacing accordingly (Kumar & Martin, 2023). However, implementation raises ethical considerations concerning privacy, data security, and biases in emotion detection algorithms (Narimisaei et al., 2024). Interdisciplinary collaboration is essential to develop transparent, bias-aware, and ethically guided AI systems that prioritize human well-being in their deployment.

Researchers continue to explore ways to enhance context-aware emotion recognition by integrating cultural, linguistic, and individual variations in emotional expression. Advancements in AEI models seek to move beyond surface-level emotion detection, incorporating behavioral patterns, sentiment analysis, and adaptive response mechanisms to create more meaningful human-machine interactions (Kambur, 2021; Narimisaei et al., 2024). Intelligent learning environments designed with AEI-driven systems could provide emotional support, personalized feedback, and dynamic engagement strategies tailored to individual students. A deeper understanding of AEI's evolution and potential allows for a more informed approach to its integration in future educational settings, ensuring that robots and AI systems are facilitators of human growth rather than mere computational tools.

Enhancing Human-Machine Synergy

The integration of AEI in robotics represents a transformative shift in human-robot interactions, expanding beyond task-based automation to socially intelligent engagement. Traditional robotics primarily focused on mechanization and efficiency, with early applications emphasizing automation in industrial and computational domains. However, as robotic applications extend into healthcare, education, and service industries, the necessity for robots to interpret and respond to human emotions has become increasingly evident (Bengani, 2023). Unlike conventional AI, AEI-driven robotics incorporates affective computing, natural language processing (NLP), and multimodal emotion recognition, enabling machines to perceive, interpret, and react to human emotions dynamically (Hudson, 2023). The advancements in cognitive robotics further allow for adaptive, context-aware responses, making interactions with AI-powered systems more intuitive and human-like (Lynch, 2021).

Developing emotionally intelligent robots requires a framework that integrates sensing, computing, and acting based on affective cues. Emotion recognition technology enables robots to capture facial expressions, voice modulation, and physiological signals, facilitating real-time emotional appraisal and response modulation (Marcos-Pablos & García-Peñalvo, 2022). Robots equipped with deep learning and reinforcement learning models refine their ability to adapt interactions based on previous human-robot exchanges, enhancing their social acceptability and functional effectiveness (Seyitoğlu & Ivanov, 2024). The emotional intelligence embedded in these systems improves user satisfaction and fosters trust and engagement, particularly in domains such as elder care, therapeutic interventions, and education. In an educational setting, AEI-driven tutors can recognize student frustration or boredom and adjust instructional methods accordingly, creating personalized learning experiences that support cognitive and emotional development (Bengani, 2023; Kumar & Martin, 2023).

Despite its promise, implementing AEI in robotics presents several technical, ethical, and philosophical challenges. Ensuring privacy, data security, and the ethical use of emotion recognition data remains a significant concern, particularly in AI-driven surveillance and algorithmic governance (Lynch, 2021). Additionally, limitations in current emotion detection algorithms, such as cultural and individual variations in emotional expression, necessitate ongoing refinement in contextual awareness (Marcos-Pablos & García-Peñalvo, 2022). As the field evolves, research must emphasize transparency and accountability in designing emotionally intelligent AI systems that enhance human-AI collaboration rather than replace human agency. Artificial Emotional Intelligence possesses the potential to revolutionize human-machine interactions, making technology more empathetic, responsive, and adaptable to diverse social contexts (Hudson, 2023).

Enhancing Human-Machine Learning

The incorporation of AEI in educational settings has the potential to revolutionize learning experiences by creating emotionally responsive and adaptive learning environments. Artificial Emotional Intelligence extends beyond traditional artificial intelligence by analyzing, interpreting, and responding to students' emotional states, fostering engagement, motivation, and personalized learning (Fernández Herrero et al., 2023). Unlike conventional AI-driven educational tools, AEI-powered systems utilize emotion recognition software, natural language processing (NLP), and multimodal affective computing to assess student emotions in real-time and adjust instructional approaches accordingly (Melweth et al., 2023; Marcos-Pablos & García-Peñalvo, 2022). Artificial Emotional Intelligence advancement aligns with research indicating that emotional intelligence is a crucial factor in academic success, as it influences students' ability to regulate emotions, engage with learning materials, and persist through challenges (Dignam & Taylor, 2024; Marcos-Pablos & García-Peñalvo, 2022).

Integrating AEI-powered learning technologies into classrooms enables adaptive feedback mechanisms that support both cognitive and emotional learning processes. Artificial Intelligence tutors equipped with affective computing capabilities can detect frustration, confusion, or disengagement and modify instructional strategies in real time, offering encouragement, hints, or alternative explanations to maintain student motivation (Erol et al., 2020; Kumar & Martin, 2023). Furthermore, emotion recognition systems facilitate teacher interventions, allowing educators to monitor student engagement and emotional responses during lessons (Hudson, 2023). Research suggests that students prefer interactive, participatory learning experiences, and AEI-powered tools can promote student-centered, emotionally attuned learning environments (Fernández Herrero et al., 2023).

Despite these benefits, implementing AEI in education presents challenges, particularly regarding data privacy, bias in emotion detection algorithms, and the ethical implications of emotional surveillance (Melweth et al., 2023). Ensuring that AEI-driven systems respect student privacy and provide accurate emotional assessments remains a priority for policymakers and educational technology developers. Additionally, ongoing refinements in DL models are needed to enhance the accuracy of emotion recognition across diverse cultural and individual differences (Marcos-Pablos & García-Peñalvo, 2022). Moving forward, collaborative efforts between educators, psychologists, and AI researchers will be essential to developing ethical, effective, and comprehensive AEI-driven educational tools that empower students both academically and emotionally (Dignam, 2025).

Figure 2 illustrates how Neural Networks, NLP, and Emotion Recognition interact within AEI systems to create adaptive, emotionally responsive learning environments. Each component possesses a distinct role in processing and interpreting human emotions: neural networks identify patterns in speech and facial expressions, NLP analyzes language and tone, and emotion recognition integrates multiple cues to assess affective states. The AEI system synthesizes these inputs, adjusting instructional strategies in real-time to enhance both cognitive and emotional engagement in educational settings.

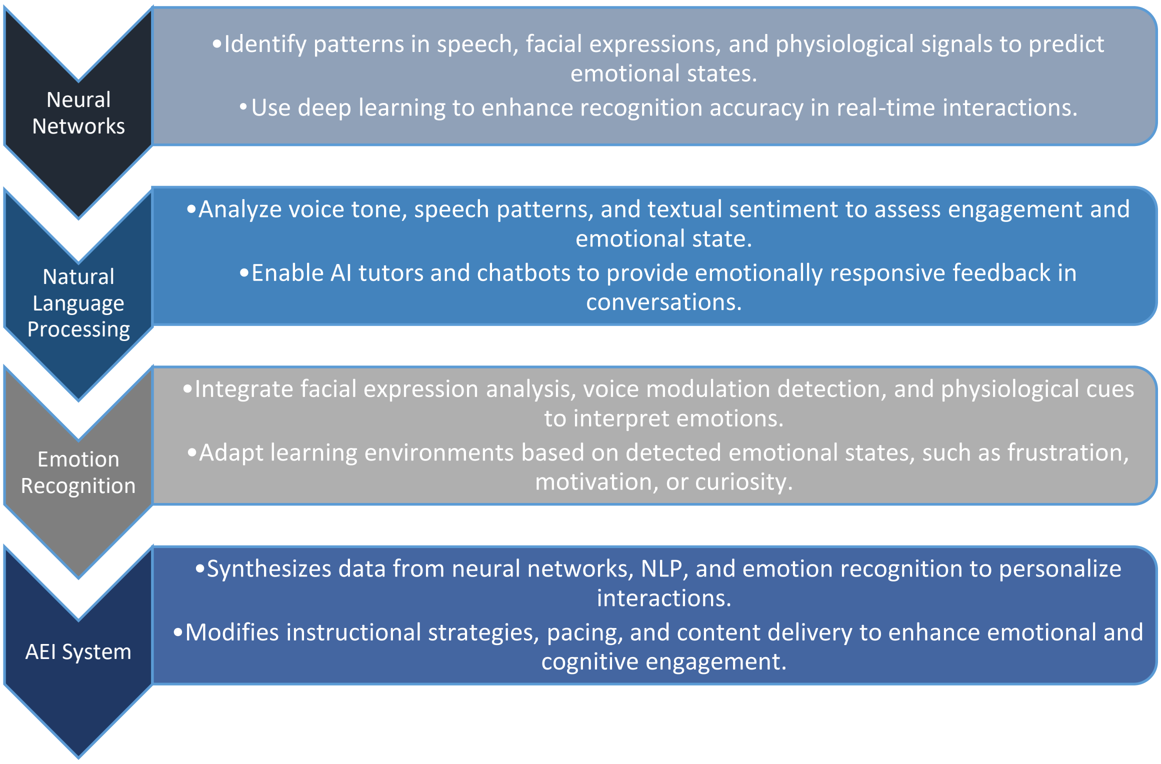

Figure 2. Neural networks and NLP in AEI

STEM to STEAM and the Art of Intelligent Machines

The integration of AEI in robotics marks a pivotal shift in how machines interact with humans, particularly in educational settings. While traditional AI has enabled automation and computational efficiency, AEI enhances robotics with emotional recognition and responsiveness, fostering deeper engagement in learning environments (Fernández Herrero et al., 2023; Marcos-Pablos & García-Peñalvo, 2022). A broader understanding of how AEI-powered robotics supports interdisciplinary learning requires an examination of the historical foundations of STEM and its evolution in education.The foundation of STEM education can be traced back to the mid-20th century, with a strong national emphasis on scientific and technological advancements following the launch of the Soviet Union’s Sputnik satellite in 1957 (Granovskiy, 2018). Concern over the United States’ scientific and engineering capabilities led to the creation of the National Aeronautics and Space Administration (NASA) in

1958, followed by major federal initiatives to strengthen STEM education (Mohr-Schroeder et al., 2015). The release of *A Nation at Risk* (1983) heightened awareness of educational reform, stressing the necessity of science, mathematics, and technological literacy to maintain global competitiveness (Mohr-Schroeder et al., 2015). These efforts culminated in Project 2061, which established science literacy benchmarks, followed by White House STEM initiatives in 2009 and 2010 (Mohr-Schroeder et al., 2015).

Global adoption of STEM education reinforced its role in preparing students for 21st-century challenges (Rifandi & Rahmi, 2019). Traditional STEM frameworks centered on science, technology, engineering, and mathematics were developed to enhance problem-solving skills, critical thinking, and innovation (Widya et al., 2019). Expanding research on cognitive and emotional learning prompted educators to recognize the value of artistic and creative disciplines, leading to the emergence of STEAM education. Integrating the arts into STEM curricula provided a more holistic approach that emphasized creativity, design, and interdisciplinary thinking (Dignam, 2024b; White, 2014).

An educational model that balances scientific inquiry, artistic expression, and emotional intelligence reflects the evolving demands of a technology-driven yet human-centered society. Philosophical STEAM education aligns with emerging advancements in AI and AEI, where empathetic, socially aware robotics play a vital role in shaping student engagement and interdisciplinary learning (Breiner et al., 2012). The blending of the arts in STEAM education and AEI-powered robotics and STEAM education transect and fosters emotionally intelligent and dynamic learning environments.

The Human Element in STEAM Education

The transition from STEM to STEAM education acknowledges that scientific and technological advancements are most impactful when they incorporate human expression, creativity, and emotional intelligence. Traditional STEM disciplines prioritize technical expertise and analytical problem-solving, while the integration of the arts introduces an essential human element, allowing students to connect deeply with content through creativity and emotional engagement (Dignam, 2024b; Perignat & Katz-Buonincontro, 2019).

The arts serve as a conduit for personal expression, cultural storytelling, and innovative thinking, enriching STEM learning by making abstract concepts tangible and emotionally resonant (Leavy et al., 2023). Through visual arts, music, drama, and creative writing, students explore scientific and mathematical principles in ways that transcend rote memorization, fostering a deeper, more intuitive grasp of complex ideas. Educational approaches that embed narrative elements and creative problem-solving have been shown to increase motivation, engagement, and retention of knowledge (Erol et al., 2023).

The power of storytelling within STEAM enhances students' imagination and problem-solving abilities and mirrors the core function of AEI for recognizing, interpreting, and responding to human emotions (Erol et al., 2023). Art allows learners to form emotional connections to their studies, and AEI-driven robotics enhances educational experiences by adapting to students' affective states, fostering motivation, and deepening engagement. Integrating artistic elements within STEM disciplines has been shown to strengthen cognitive, social, and emotional learning, enriching students' ability to connect abstract scientific concepts with personal experiences (Dignam, 2024b).

The personalization afforded by AEI aligns with the transformative potential of STEAM, where students are encouraged to integrate emotional and creative dimensions into their learning (Larkin, 2015). Understanding how the arts evoke emotional connections makes it clear that AEI and STEAM education share a common goal of humanizing learning through emotion, perception, and creativity (Leavy et al., 2023). The integration of music and artistic expression into STEM education further supports engagement by fostering deeper intellectual curiosity and cognitive flexibility (Dignam, 2024b). As interdisciplinary and transdisciplinary frameworks continue to evolve, the intersection of STEAM and AEI presents a novel pathway for nurturing leadership, social-emotional learning, and problem-solving abilities across various educational settings (Dignam, 2024a).

Emotional Connections in STEAM

Science, technology, engineering, art, mathematics education, and AEI-driven robotics create meaningful emotional connections by allowing students to engage with content in creative, expressive, and immersive ways. The integration of the arts, storytelling, and digital expression within STEM disciplines has demonstrated its ability to strengthen cognitive engagement and social-emotional learning (Leavy et al., 2023). Artificial emotional intelligence enhances student interactions by adapting to emotional cues, storytelling, and artistic expression, providing avenues for students to connect with learning material on a personal level. These elements become even more impactful when approached through interdisciplinary and transdisciplinary education, which encourages synthesis across multiple disciplines to create deeper, more meaningful learning experiences (Barth et al., 2023; Liao, 2016).

Figure 3 illustrates the interconnected relationship between STEAM education, AEI and robotics, storytelling and digital expression, and emotional connections through SEL. Each quadrant of the clover-shaped Venn diagram represents a distinct yet complementary domain that contributes to an adaptive and emotionally intelligent learning environment. Positioned in the north, STEAM education emphasizes innovation, creativity, critical thinking, and problem-solving, equipping students with the skills necessary for interdisciplinary exploration. To the south, AEI and robotics focus on emotion recognition, adaptive AI, and personalized learning, enabling technology to respond to students' affective states and foster engagement. On the east side, storytelling and digital expression integrate narrative learning, multimodal engagement, and the arts, offering students opportunities to construct meaning, communicate complex ideas, and engage in creative inquiry. The west quadrant highlights emotional connections and SEL, which fosters empathy, motivation, social-emotional learning, and personalized growth, reinforcing the human-centered aspects of education.

The center of the figure represents the fusion of these four domains, emphasizing emotionally intelligent, interdisciplinary, and creative learning environments. Integrating STEAM education with AEI-driven robotics allows students to engage in inquiry-based and problem-solving experiences that are both technologically advanced and emotionally responsive. Storytelling and digital expression strengthen the connections between knowledge and lived experiences, reinforcing deeper engagement and critical thinking. Emotional connections and SEL ensure that learning remains meaningful, culturally relevant, and personalized to students' needs. The convergence of these elements creates a balanced educational model that supports intellectual curiosity, social awareness, and creative problem-solving, preparing students to navigate complex challenges with adaptability and emotional intelligence.

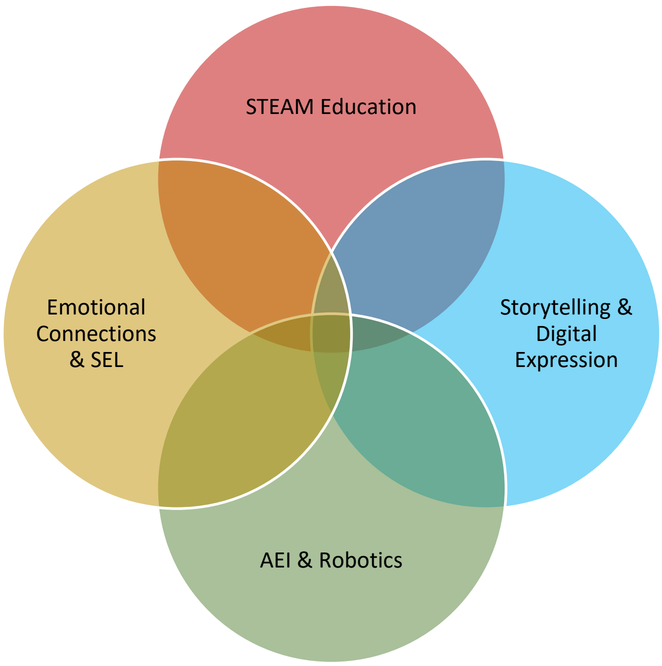

Figure 3. STEAM, AEI, storytelling, and SEL connections

Interdisciplinary and Transdisciplinary Learning in STEAM

Interdisciplinary and transdisciplinary approaches are essential to modern STEAM education, as they promote synthesized learning experiences that connect traditionally disparate fields. Interdisciplinary learning involves the blending of multiple subject areas, allowing students to draw insights across different disciplines to solve complex problems (Yang et al., 2022).

For example, a STEAM lesson may integrate engineering principles with artistic design, enabling students to engage in creative problem-solving that mirrors real-world innovation (Liao, 2016). Transdisciplinary learning moves beyond subject integration to create seamless, holistic educational experiences that prioritize real-world applications and learner-driven inquiry (Clark & Button, 2011). A transdisciplinary approach fosters collaboration between domains, preparing students to address complex challenges that require adaptability, critical thinking, and innovation (Barth et al., 2023).

Digital storytelling serves as a key tool within interdisciplinary and transdisciplinary STEAM education, allowing students to craft narratives that merge technology, personal experience, and academic content (Yang et al., 2022). Robotics and AI-driven learning platforms expand this storytelling potential by offering emotionally intelligent, interactive experiences that enable students to engage with content innovatively (Jia et al., 2023). Research indicates that students engaged in digital storytelling within interdisciplinary projects demonstrate enhanced critical thinking, creativity, and collaboration, as they must synthesize ideas across disciplines (Dignam, 2024a).

The emotional connections formed through STEAM storytelling and AEI-powered robotics reinforce the importance of teaching and learning approaches that emphasize collaboration, creativity, and human-centered engagement. Interdisciplinary and transdisciplinary learning, emotional intelligence, and digital storytelling will continue to redefine educational methodologies, ensuring that STEAM education remains dynamic, relevant, and deeply connected to students' lived experiences (Clark & Button, 2011; Barth et al., 2023).

The Art and Science of Learning through Experience

Vygotsky (1978) posits student acquisition of knowledge results through social interactions, resulting in the construction of knowledge. Vygotsky's constructivist paradigm links students' social interactions during hands-on activities, such as interacting with AI robotics, to constructing meaningful understanding for knowledge-building. Kolb et al. (1984) theorized the act of learning includes a four-part cycle that includes concrete experience, reflective observation, abstract conceptualization, and active experimentation for acquiring knowledge. In addition, cognition via experiential learning is exemplified when students demonstrate knowledge by applying concepts, such as during robotics, to learning (Kolb, 2014). Constructing and experiencing are key for meaningful STEAM-AEI knowledge building.

Interdisciplinary and transdisciplinary approaches in STEAM education establish a foundation for deeper engagement in discovery learning, experiential learning, and constructivism. These pedagogical frameworks emphasize hands-on, student-centered learning that fosters critical thinking and real-world problem-solving. Kolb's experiential learning model, which includes concrete experience, reflective observation, abstract conceptualization, and active experimentation, aligns with interdisciplinary and transdisciplinary STEAM education by providing students with opportunities to engage in inquiry-based learning that connects theory to practice (Kolb, 2014; Nguyen et al., 2020).

Social constructivist learning theory, particularly Vygotsky's perspective, accentuates the importance of collaboration, dialogue, and the co-construction of knowledge. The Zone of Proximal Development (ZPD) suggests that students learn best when engaging in tasks slightly beyond their current ability, supported by peers or instructors (Saleem et al., 2021; Vygotsky, 1978). Interdisciplinary and transdisciplinary STEAM learning fosters cooperative inquiry, where students actively construct knowledge through experiential learning and digital storytelling (Remington et al., 2023).

Discovery learning, a concept advanced by Bruner (1996) and Piaget (1972), reinforces problem-solving and active exploration in education. Within STEAM disciplines, students engage in design challenges requiring hypothesis formation, experimentation, and refinement of understanding (Efgivia et al., 2021). Transdisciplinary learning advances this concept by removing rigid subject barriers, integrating real-world contexts, and promoting holistic approaches to knowledge acquisition (Jia et al., 2023).

Kolb's experiential learning theory emphasizes the need for meaningful engagement, encouraging students to cycle through experiencing, reflecting, conceptualizing, and applying knowledge to new situations (Kolb et al., 1984; Nguyen et al., 2020). Active participation in hands-on learning environments within STEM and STEAM education reinforces the practical application of knowledge, strengthening students' ability to construct understanding through real-world interactions (Budiyanto et al., 2020).

A deeper sense of agency in learning develops through discovery learning, experiential learning, and constructivism in interdisciplinary and transdisciplinary STEAM education. Robotics, AEI, and digital storytelling further enhance this process by providing interactive, emotionally responsive learning experiences that bridge disciplines and foster creativity (Saleem et al., 2021). Integrated approaches to education ensure that students develop both technical competencies and the ability to think critically, adaptively, and creatively in an evolving world (Remington et al., 2023).

Sense of Agency in Learning

Figure 4 illustrates the role of Sense of Agency in Learning as the central force connecting six key learning approaches that empower students to take ownership of their education. Positioned at the center, Sense of Agency in Learning represents adaptability, innovation, and student-driven learning, emphasizing how individuals actively engage with content, apply knowledge, and navigate challenges in meaningful ways. Each surrounding element contributes to fostering a sense of agency by providing distinct yet interconnected pathways for exploration, application, and reflection.

Discovery Learning, located at the top (12 o'clock), serves as the entry point for exploration, inquiry, and hypothesis testing. Positioned at 2 o'clock, Experiential Learning reinforces real-world application, allowing students to engage hands-on with concepts and refine their understanding through practice and reflection. Constructivism, situated at 4 o'clock, highlights the social and cognitive dimensions of learning by promoting collaborative meaning-making and critical thinking. At 6 o'clock, Digital Storytelling integrates creativity, narrative engagement, and multimodal expression, enabling students to personalize their learning experiences. Artificial Emotional Intelligence (AEI), placed at 8 o'clock, fosters emotionally responsive and adaptive interactions, ensuring that students remain engaged, supported, and motivated in learning. Finally, Robotics, positioned at 10 o'clock, enhances problem-solving through technology-driven experiences, encouraging students to develop computational thinking and hands-on engineering skills. Together, these six elements interconnect at the center, where agency is cultivated through interdisciplinary and transdisciplinary learning, reinforcing the importance of student autonomy, engagement, and innovative thinking in STEAM education.

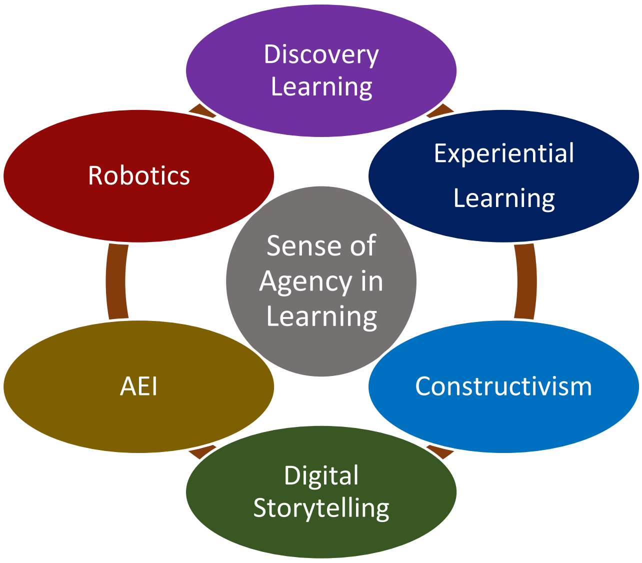

Figure 4. Sense of agency in learning

The Role of Robotics in Experiential Learning

Educational robotics serves as a powerful tool for fostering experiential learning, aligning with constructivist principles that emphasize active engagement and real-world application. Robotics-based activities encourage students to develop problem-solving skills, enhance critical thinking, and engage in collaborative learning environments where they can test hypotheses and refine their approaches (Miglino et al., 1999). When students interact with programmable robots and AI-driven systems, learners move beyond passive consumption of information, instead taking on the role of designers, engineers, and computational thinkers (Uslu et al., 2023).

Research indicates that AI and robotics significantly impact cognitive, social-emotional, and intellectual learning outcomes, reinforcing their role as essential components of experiential education (Salas-Pilco, 2020). Robotics platforms designed for educational use enhance student motivation, engagement, and adaptability, providing a bridge between theoretical knowledge and real-world application (Hsu et al., 2021). These tools create an iterative learning cycle where students can prototype, test, and refine solutions, reinforcing the engineering design process while fostering growth in computational thinking and problem-solving skills.

Beyond cognitive benefits, robotics cultivates social-emotional learning by promoting teamwork, communication, and adaptability. Collaborative robotics projects encourage students to negotiate roles, share ideas, and navigate challenges, mirroring real-world interdisciplinary problem-solving scenarios (Uslu et al., 2023). Additionally, AEI-powered robotics enhances personalized learning experiences by adapting to students' affective states, responding to their needs, and providing emotionally intelligent feedback that reinforces persistence and resilience (Salas-Pilco, 2020).

The integration of robotics in experiential learning environments possesses the potential to bridge STEM concepts with real-world applications, ultimately preparing students for future careers that require adaptability, creativity, and interdisciplinary thinking. As AI and AEI-driven robotics continue to evolve, their impact on educational methodologies and student engagement offers new pathways for authentic, hands-on learning experiences across all levels of education.

Integration of Robotics in Early Childhood Education

Robotics in early childhood education serves as an engaging tool for fostering cognitive, social, and technological development. Research indicates that introducing robotics at an early age enhances problem-solving abilities, computational thinking, and creativity, positioning young learners to develop essential twenty-first-century skills (Zviel-Girshin et al., 2020). Through hands-on engagement with robotics, children build confidence in technology use while simultaneously strengthening their ability to work collaboratively and think critically. Programs that integrate educational robotics into early learning environments have demonstrated positive outcomes in children's ability to engage with engineering concepts in meaningful ways, reinforcing the role of robotics as a developmental asset (Canbeldek & Isikoglu, 2022).

The combination of robotics and STEAM education in early childhood provides children with opportunities to develop computational thinking through interactive and play-based learning. Robotics activities allow young learners to experiment with sequencing, algorithmic design, and logical reasoning, creating a foundation for later STEM learning (Chaldi & Mantzanidou, 2021). Research further emphasizes the importance of early childhood educators' perspectives in shaping how robotics is introduced in preschool and primary education settings (Gavrilas et al., 2024).

The willingness of teachers to integrate robotics into early childhood education influences both student engagement and curriculum design, emphasizing the necessity for teacher preparation and ongoing professional learning in educational robotics. As a result, children exposed to robotics programs demonstrate higher levels of engagement and motivation in problem-solving tasks, making the integration of robotics in early education a promising strategy for fostering early digital literacy and creativity (Papadakis et al., 2021).

Robotics also facilitates experiential learning by enabling children to interact with digital tools in ways that connect with their natural curiosity. Coding and robotics programs tailored for early childhood have been shown to enhance both cognitive and social development by promoting exploratory learning environments (Canbeldek & Isikoglu, 2022). The hands-on nature of robotics supports inquiry-based learning while fostering collaboration among young learners, ultimately enhancing problem-solving and decision-making skills (Chaldi & Mantzanidou, 2021). Research suggests that early exposure to robotics fosters confidence in using technology, leading to long-term benefits as children progress through their education (Gavrilas et al., 2024). Through these interactive experiences, young children gain early exposure to technological fluency, setting the stage for continued engagement with STEAM fields as they advance academically.

Fostering Critical Thinking and Teamwork in K-12 Education

Educational robotics has become an essential tool in kindergarten through twelfth-grade (K-12) education, fostering critical thinking and teamwork through hands-on, inquiry-based learning experiences. Research highlights the role of robotics in engaging students in computational problem-solving while developing their ability to analyze, design, and implement creative solutions (Jurado et al., 2020). The integration of robotics into the curriculum provides students with opportunities to work collaboratively on STEM-related projects, reinforcing both cognitive and interpersonal skills (Safrudin et al., 2021). Robotics activities in classrooms encourage iterative learning, where students test hypotheses, troubleshoot errors, and refine their approaches, ultimately strengthening their ability to think critically and work effectively within teams (Sisman et al., 2021).

Collaboration is central to educational robotics, as students must communicate ideas, delegate responsibilities, and collectively resolve challenges throughout the design and programming process (Jurado et al., 2020). In many cases, students engage in structured group work where roles such as programmer, builder, and researcher are assigned, requiring them to practice both leadership and cooperation skills (Fonseca et al., 2020). Studies indicate that a programmer, builder, researcher, and collaborative dynamic not only improves problem-solving capabilities but also enhances students' confidence in STEM subjects, particularly among those who may initially feel apprehensive about technology-focused learning (Sisman et al., 2021).

Beyond fostering critical thinking, robotics education is pivotal in preparing students for future careers that demand interdisciplinary competencies. The use of robotics in K-12 settings has been shown to improve spatial reasoning, logical thinking, and creativity. An intrinsic ability to engage in spatial reasoning, logical thinking, and creativity is a key element of both STEM education and broader workforce readiness (Safrudin et al., 2021).

Robotics curricula frequently incorporate elements of design thinking, engineering principles, and algorithmic logic, providing students with a multifaceted learning experience that bridges theoretical knowledge with practical application (Fonseca et al., 2020). As robotics continues to be integrated into modern classrooms, its potential to support holistic student development through collaborative and inquiry-based learning remains a key area of focus for educators and policymakers.

Incorporating Robotics in Higher Education

Robotics has become an integral component of higher education, particularly in engineering, computer science, and STEAM disciplines. Universities are increasingly embedding robotics into curricula to promote hands-on learning, problem-solving, and innovation-driven education (Ahmad, 2020). A scenario-based approach to integrating robotics into coursework prepares students for future workforce demands, ensuring that graduates develop practical skills in automation, artificial intelligence, and interdisciplinary collaboration (Kucuk & Sisman, 2020). Robotics education at the university level often employs project-based and challenge-based learning models, allowing students to engage in real-world problem-solving and industry-relevant applications (Tselegkaridis & Sapounidis, 2021).

The use of robotic simulators and physical robotic platforms enables students to develop technical competencies in coding, mechanics, and AI-driven automation without the limitations of hardware constraints (Tselegkaridis & Sapounidis, 2021). Research suggests that the integration of robotics in university settings enhances student engagement and motivation, particularly when combined with experiential learning approaches (Conde et al., 2021). Studies also highlight that students with prior exposure to robotics in pre-kindergarten through twelfth-grade (PK-12) settings demonstrate increased confidence and performance in higher education robotics courses, reinforcing the value of early exposure and continued application throughout a student's academic trajectory (Kucuk & Sisman, 2020).Beyond technical skill development, robotics in higher education fosters collaborative learning and interdisciplinary, transdisciplinary exploration. Programs that incorporate robotics within STEAM and AI curricula emphasize the intersection of technology, creativity, and problem-solving, allowing students to work across disciplines and develop adaptive learning strategies (Cox, 2021). As AI continues to evolve, robotics courses increasingly integrate AI-driven decision-making models, preparing students to apply ML, automation, and human-robot interaction principles to real-world applications (Ahmad, 2020).

The ongoing expansion of robotics in higher education curriculum design is significant in preparing students for the demands of modern industries. Research supports the need for institutional investment in robotics laboratories, interdisciplinary programs, and AI-enhanced learning tools to ensure that students gain the skills necessary for an increasingly automated world (Conde et al., 2021). As universities continue to refine their robotics offerings, collaborative partnerships between academia and industry will further strengthen opportunities for students to engage in cutting-edge research, internships, and applied learning experiences that bridge theory and practice (Cox, 2021).

Table 2 provides an overview of how robotics, AI, and AEI are applied across different educational levels, from early childhood to higher education. The table outlines the distinct applications of robotics and AI at each stage, emphasizing their role in fostering problem-solving, computational thinking, teamwork, and interdisciplinary learning. Artificial Emotional Intelligence-driven systems further enhance these experiences by providing emotionally responsive interactions that adapt to students' needs, supporting engagement, motivation, and personalized learning. The progression of robotics and AI across educational levels illustrates how these technologies evolve to meet increasingly complex cognitive, social, and technical demands. Table 2 serves as a comparative reference for examining the developmental impact of robotics and AI integration throughout the educational continuum.

Table 2. Robotics, AI, and AEI across education levels

Educational Level	**Robotics & AI Applications**	**Key Benefits**	**AEI Integration**
Early Childhood	Play-based robotics, coding tools	Enhances problem-solving, computational thinking, creativity	Emotionally responsive interactions to support engagement and early learning
K-12 Education	STEM/STEAM robotics projects, collaborative programming	Develops critical thinking, teamwork, and design-based problem-solving	AEI-driven feedback for adaptive learning and motivation
Higher Education	AI-powered robotics, interdisciplinary applications	Advances technical proficiency, research skills, and workforce readiness	Human-robot interaction, AI decision-making models, and ethical AI considerations

Conceptual Framework

The integration of artificial emotional intelligence (AEI) and robotics in education is grounded in constructivist, experiential, interdisciplinary, and transdisciplinary learning theories, which emphasize active engagement, social interaction, and adaptive learning. A constructivist, experiential, interdisciplinary, and transdisciplinary framework synthesizes research on AI, robotics, and emotional intelligence to examine how AEI-powered systems enhance student motivation, engagement, and collaboration while addressing the pedagogical challenges associated with emerging technologies.

A constructivist perspective encapsulates the value of hands-on, inquiry-based learning, where students construct knowledge through interaction with adaptive technologies. Vygotsky's (1978) Zone of Proximal Development (ZPD) highlights the importance of scaffolded and interactive experiences aligning with robotics education, where learners engage in exploration, experimentation, and iterative problem-solving. Artificial Emotional Intelligence enhances this process by enabling emotionally responsive interactions, reinforcing student engagement and self-regulated learning. The ability of AEI-powered robotics to recognize affective cues, adjust responses, and support perseverance in problem-solving tasks introduces a dynamic, student-centered feedback loop. Kolb's (2014) experiential learning theory further supports the integration of AEI robotics, emphasizing the cyclical nature of learning through concrete experience, reflective observation, abstract conceptualization, and active experimentation. Robotics-based activities align with this model as students engage with technology, analyze feedback, and refine solutions in an iterative manner. The introduction of AEI in robotics expands experiential learning by providing emotionally attuned interactions, fostering greater motivation and deeper cognitive engagement.

Interdisciplinary and transdisciplinary STEAM education frameworks provide another foundational layer for AEI robotics. The inclusion of science, technology, engineering, the arts, and mathematics supports creativity, innovation, and holistic learning (Perignat & Katz-Buonincontro, 2019). The artistic and emotional dimensions of STEAM align with AEI's ability to humanize technology, allowing students to develop cognitive and emotional connections to their learning experiences. Digital storytelling, robotics-based artistic projects, and adaptive AI tutors illustrate how AEI enhances creative problem-solving within STEAM disciplines.

The conceptual framework developed in this study positions AEI-powered robotics at the hub of constructivist, experiential, interdisciplinary, and transdisciplinary learning theories. Emotionally intelligent robotics extends beyond automation by fostering adaptive, socially responsive, and emotionally aware learning environments across early childhood, K-12, and higher education. The application of AI, emotion recognition, and human-computer interaction creates new opportunities to enhance engagement, collaboration, and personalized learning pathways.

Results and Discussion

The integration of AEI and robotics in education presents significant findings related to student engagement, cognitive development, social-emotional learning, and interdisciplinary applications. The analysis examines how AEI-driven robotics enhances learning experiences across early childhood, K-12, and higher education, emphasizing its role in personalized instruction, adaptive learning environments, and collaboration.

Impact of AEI and Robotics on Student Engagement and Motivation

Artificial intelligence and AEI-driven robotics contribute to heightened student engagement and motivation, particularly by fostering interactive, responsive, and adaptive learning environments. Emotionally intelligent robotics adjusts instructional strategies based on learners' affective states, reinforcing personalized learning experiences and increasing persistence in problem-solving tasks (Salas-Pilco, 2020; Uslu et al., 2023). The ability of AEI to adapt in real-time enhances engagement by addressing student frustration and maintaining curiosity, which aligns with constructivist and experiential learning theories (Bruner, 1997; Kolb, 2014; Piaget, 1972; Vygotsky, 1978).

Artificial Emotional Intelligence-powered robotics demonstrates particular effectiveness in early childhood settings, where interactive and play-based learning strengthens cognitive and emotional engagement. Research indicates that young learners respond with increased enthusiasm when robotics is introduced through storytelling, hands-on problem-solving, and peer collaboration, which supports early STEM literacy (Gavrilas et al., 2024). Similarly, studies highlight that PK-12 students engaged in robotics-infused learning environments exhibit greater motivation and perseverance, particularly when collaborative projects and gamified challenges are incorporated (Jurado et al., 2020). In higher education, robotics integration promotes self-directed learning, equipping students with critical thinking skills and technological proficiency necessary for careers in AI, engineering, and interdisciplinary research (Kucuk & Sisman, 2020).

Cognitive Development and Interdisciplinary Learning Outcomes

Findings indicate that robotics supports cognitive development by reinforcing computational thinking, logical reasoning, and problem-solving skills. Engaging students in iterative design cycles where learners construct, test, and refine solutions fosters metacognitive growth and higher-order thinking abilities (Safrudin et al., 2021). Artificial Emotional Intelligence further enhances cognitive engagement by incorporating emotionally responsive interactions, ensuring that learning remains personalized and adaptive (Perignat & Katz-Buonincontro, 2019). At the early childhood level, robotics enhances spatial reasoning and algorithmic thinking by encouraging interactive play and hands-on exploration. Research suggests that young children who engage in robotics-based learning environments develop foundational skills in logic, coding, and digital literacy, positioning them for future STEM engagement (Canbeldek & Isikoglu, 2022; Chaldi & Mantzanidou, 2021).

For PK-12 learners, robotics integrates abstract STEM concepts with creative problem-solving, reinforcing design thinking and interdisciplinary collaboration (Dignam, 2024a). Engaging in robotics competitions and team-based engineering challenges improves student confidence in problem-solving and computational reasoning, further strengthening interdisciplinary learning (Sisman et al., 2021). At the higher education level, robotics serves as a catalyst for cross-disciplinary innovation, allowing students from computer science, engineering, arts, and cognitive sciences to explore human-robot interaction, ethical AI applications, and adaptive learning research (Cox, 2021). The inclusion of robotics-integrated curricula enhances students' analytical reasoning and professional readiness, equipping learners with the interdisciplinary competencies needed for emerging AI-driven fields (Ahmad, 2020).

Social-Emotional Learning and Human-Robot Interaction

AEI-powered robotics significantly contributes to SEL by fostering emotionally responsive, cooperative, and communicative learning environments. Studies suggest that emotionally intelligent robotics encourages students to develop teamwork, empathy, and social awareness, reinforcing the importance of collaborative problem-solving (Salas-Pilco, 2020). For early childhood learners, interactive robotics programs support emotional regulation and peer collaboration, particularly through structured play and cooperative storytelling (Gavrilas et al., 2024). Studies indicate that young learners engaged with emotionally responsive robots develop greater social awareness, improved communication skills, and increased confidence in peer interactions (Papadakis et al., 2021).

Within PK-12 education, AEI-powered robotics enhances team-based learning, where students negotiate roles, solve problems collectively, and strengthen leadership skills. Research highlights that robotics-integrated SEL interventions improve students' ability to manage conflict, engage in effective communication, and collaborate on complex challenges (Jurado et al., 2020; Sisman et al., 2021). In higher education, robotics programs incorporating human-robot interaction (HRI) frameworks enable students to explore adaptive AI, emotional intelligence in technology, and ethical considerations in AI-human collaboration (Tselegkaridis & Sapounidis, 2021). Studies indicate that students engaging with AEI-driven robotics acquire skills in ethical AI design, human-centered engineering, and interdisciplinary problem-solving, preparing them for leadership in technology and education (Kucuk & Sisman, 2020).

Challenges and Considerations for AEI-Powered Robotics in Education

The integration of AEI-powered robotics presents challenges related to ethical concerns, accessibility, and technological limitations. Privacy issues surrounding emotion recognition algorithms, as well as affective computing, require continued refinement to ensure welcoming learning experiences (Hudson, 2023). Research highlights that cultural and linguistic differences must be addressed in AEI robotics to positively influence emotional assessments and student feedback (Marcos-Pablos & García-Peñalvo, 2022).

Findings also indicate that disparities in robotics access are derived from underfunded schools and rural communities. While robotics adoption has increased at the higher education level, accessibility remains limited in early childhood and K-12 settings, where resource constraints and professional growth gaps affect implementation (Dignam, 2024a). Educators and policymakers must prioritize infrastructure development, teacher training, and ethical AI frameworks to ensure responsible integration of AEI-powered robotics. Future research should continue exploring adaptive learning models, interdisciplinary AI applications, and human-robot interaction, shaping the ongoing evolution of robotics in education (Conde et al., 2021).

Conclusion

The integration of AEI in educational robotics presents new possibilities for enhancing student engagement, cognitive development, and SEL across early childhood, K-12, and higher education settings. Emotionally intelligent robotics supports personalized, adaptive instruction by recognizing affective cues and adjusting responses, accordingly, reinforcing constructivist and experiential learning approaches. The findings of this study suggest that AEI-powered robotics fosters curiosity, problem-solving, and interdisciplinary collaboration while also addressing social-emotional competencies through cooperative learning experiences. Students interacting with emotionally responsive robotics develop enhanced motivation, perseverance, and self-regulated learning behaviors, reinforcing the potential for AI-driven systems to support both academic and personal growth.

Despite its benefits, the implementation of AEI-powered robotics requires careful consideration of ethical, accessibility, and pedagogical challenges. The refinement of emotion recognition technologies remains essential to ensure that AEI-driven systems provide accurate assessments of student affective states. Addressing disparities in access to robotics-based education is necessary to ensure access to technology-enhanced learning environments. Additionally, educators require specialized training to effectively integrate AI and robotics into classroom instruction, ensuring that adaptive learning models align with best practices in pedagogy and interdisciplinary education.

Artificial emotional intelligence represents a shift toward a more human-centered approach to educational robotics, prioritizing adaptive, emotionally attuned interactions that enhance engagement, collaboration, and cognitive development. Future research on human-robot interaction, interdisciplinary applications, and ethical considerations will be instrumental in shaping the responsible integration of AEI-powered robotics in educational settings. A commitment to ongoing evaluation, refinement, and professional growth will ensure that emotionally intelligent AI systems remain valuable tools in fostering meaningful, student-centered learning experiences.

Recommendations

The advancement of AEI-powered robotics in education necessitates further research and strategic implementation to maximize its potential while addressing ethical and pedagogical concerns. Emotion recognition technologies must be refined to identify a range of affective expressions, making it imperative that AEI algorithms are trained to recognize and respond to emotional variations with accuracy and precision. Transparent AI development and interdisciplinary collaboration will contribute to more ethically guided robotics applications in education.

The expansion of robotics access in early childhood, K-12, and higher education settings remains a priority to prevent disparities in technology-enhanced learning. Schools and universities must invest in infrastructure that supports the integration of AI and robotics within interdisciplinary and transdisciplinary curricula, ensuring that students have opportunities to engage in robotics-based learning. Teacher preparation programs should incorporate training in AI literacy and robotics pedagogy, equipping educators with the knowledge and skills necessary to facilitate adaptive, emotionally responsive instruction. Professional growth initiatives should provide ongoing support for educators, reinforcing best practices in interdisciplinary and transdisciplinary teaching and experiential, constructivist learning models that align with AI-enhanced education.

Interdisciplinary and transdisciplinary education offer opportunities for integrating AEI-powered robotics within broader learning frameworks. Emotionally intelligent robotics supports the fusion of STEM, the arts, and human-centered AI applications, allowing students to explore connections between technology, creativity, and social-emotional learning. Digital storytelling, interactive design, and human-robot collaboration provide avenues for deepening engagement and fostering critical thinking in students. The continued exploration of AEI within interdisciplinary education will contribute to a more dynamic and adaptive learning environment that strengthens students' ability to navigate complex, real-world challenges.

Ongoing research into human-robot interaction will be essential for refining the role of AEI-powered robotics in education. Longitudinal studies that examine student engagement, academic achievement, and SEL outcomes will provide valuable insights into the effectiveness of emotionally intelligent AI systems. Exploring applications for AEI in special education can further enhance personalized learning opportunities, allowing adaptive robotics to support students with diverse needs through individualized feedback and scaffolding. Ethical considerations related to AI-driven emotional recognition, privacy, and decision-making should remain central to discussions on the integration of AEI in education.

A comprehensive approach to AEI-driven robotics in education requires collaboration among educators, researchers, and policymakers to ensure responsible and effective implementation. Prioritizing transparency and interdisciplinary and transdisciplinary learning will contribute to a more transformative educational landscape where emotionally intelligent robotics enhances both cognitive and social-emotional development.

Scientific Ethics Declaration

The authors declare that the scientific, ethical, and legal responsibility of this article published in JESEH journal belongs to the authors.

Conflict of Interest

The authors declare that they have no conflicts of interest

Funding Declaration

The authors did not receive support from any organization for the submitted work.

References

Ahmad, T. (2020). Scenario based approach to re-imagining future of higher education which prepares students for the future of work. *Higher Education, Skills and Work-Based Learning*, *10*(1), 217-238.

Barth, M., & Mascarenhas, A. (2023). Transdisciplinary learning as a key leverage for sustainability transformations. *Current Opinion in Environmental Sustainability*, 64, 101361.

Bengani, V. (2024). AI-driven emotional intelligence for enhanced human-robot interaction. https://www.researchgate.net/profile/Vedika-Bengani/publication/382523407_AI_Driven_Emotional_Intelligence_ for_Enhanced_Human-_Robot_Interaction/links/66a13d0527b00e0ca43e3d63/AI-Driven-Emotional-Intelligence-for-Enhanced-Human-Robot-Interaction.pdf

Breiner, J. M., Harkness, S. S., Johnson, C. C., & Koehler, C. M. (2012). What is STEM? A discussion about conceptions of STEM in education and partnerships. *School Science and Mathematics*, *112*(1), 3-11.

Bruner, J. (1996). *The culture of education*. Cambridge, MA: Harvard University Press.

Budiyanto, C., Fitriyaningsih, R. N., Kamal, F., Ariyuana, R., & Efendi, A. (2020). Hands-on learning in STEM: revisiting educational robotics as a learning style precursor. *Open Engineering*, *10*(1), 649-657.

Canbeldek, M., & Isikoglu, N. (2023). Exploring the effects of productive children: Coding and robotics education program in early childhood education. *Education and Information Technologies*, *28*(3), 3359-3379.

Cebollada, S., Payá, L., Flores, M., Peidró, A., & Reinoso, O. (2021). A state-of-the-art review on mobile robotics tasks using artificial intelligence and visual data. *Expert Systems with Applications*, *167*, 114195.

Chaldi, D., & Mantzanidou, G. (2021). Educational robotics and STEAM in early childhood education. *Advances in Mobile Learning Educational Research*, *1*(2), 72-81.

Clark, B., & Button, C. (2011). Sustainability transdisciplinary education model: Interface of arts, science, and community (STEM). *International Journal of Sustainability in Higher Education*, *12*(1), 49-60.

Conde, M. Á., Rodríguez-Sedano, F. J., Fernández-Llamas, C., Gonçalves, J., Lima, J., & García-Peñalvo, F. J. (2021). Fostering STEAM through challenge-based learning, robotics, and physical devices: A systematic mapping literature review. *Computer Applications in Engineering Education*, *29*(1), 46-65.

Cox, A. M. (2021). Exploring the impact of Artificial Intelligence and robots on higher education through literature-based design fictions. *International Journal of Educational Technology in Higher Education*, *18*(1), 3.

Dignam C., & Taylor, D. (2024). Beyond the acronym: Entwining STEAM education, self-regulation, and mindfulness. *Journal of STEAM Education, 7*(2), 159-190.

Dignam, C. (2024a). Beyond the acronym: Intersections of STEAM, cybernetics, and leadership nurturing. *Journal of Education in Science, Environment and Health (JESEH)*, *10*(2), 155-170.

Dignam, C. (2024b). Harmonies on the string: Exploring the synergy of music and STEM. *International Journal of Technology in Education and Science*, *8*(3), 491-521.

Dignam, C. (2025). Makerspace and the 5C's of learning: Constructing, communicating, collaborating, critically-thinking, and creatively-thinking. *International Journal of Studies in Education and Science, 6*(1), 104-127.

Efgivia, M. G., Rinanda, R. A., Hidayat, A., Maulana, I., & Budiarjo, A. (2021, October). Analysis of constructivism learning theory. In *1st UMGESHIC International Seminar on Health, Social Science and Humanities* (pp. 208-212).

Erol, A., Erol, M., & Basaran, M. (2023). The effect of STEAM education with tales on problem solving and creativity skills. *European Early Childhood Education Research Journal, 31*(2), 243-258.

Erol, B. A., Majumdar, A., Benavidez, P., Rad, P., Choo, K. K. R., & Jamshidi, M. (2019). Toward artificial emotional intelligence for cooperative social human–machine interaction. *IEEE Transactions on Computational Social Systems*, *7*(1), 234-246.

Fernández Herrero, J., Gómez Donoso, F., & Roig Vila, R. (2023). The first steps for adapting an artificial intelligence emotion expression recognition software for emotional management in the educational context. *British Journal of Educational Technology*, *54*(6), 1939-1963.

Gavrilas, L., Kotsis, K. T., & Papanikolaou, M.-S. (2024). Exploration of the prospective utilization of educational robotics by preschool and primary education teachers. *Pedagogical Research, 9*(1), em0181.

Granovskiy, B. (2018). Science, technology, engineering, and mathematics (STEM) education: An overview. CRS Report R45223, Version 4. Updated. *Congressional Research Service.*

Groumpos, P. P. (2021). A critical historical and scientific overview of all industrial revolutions. *IFAC-PapersOnLine*, *54*(13), 464-471.

Hsu, T. C., Abelson, H., Lao, N., & Chen, S. C. (2021). Is it possible for young students to learn the AI-STEAM application with experiential learning? *Sustainability*, *13*, 11114.

Hudson, S. (2020). *Artificial intelligence, cognitive robotics and human psychology*. DO, 2(20153.52323): 10.13140

Jafari, N., Azarian, M., & Yu, H. (2022). Moving from Industry 4.0 to Industry 5.0: What are the implications for smart logistics?. *Logistics*, *6*(2), 26.

Jia, X., Li, W., & Wang, Y. (2023). A curriculum integrating STEAM and maker education promotes pupils' learning motivation, self-efficacy, and interdisciplinary knowledge acquisition. *International Journal of Science Education*, 45(3), 412-428.

Jurado, E., Fonseca, D., Coderch, J., & Canaleta, X. (2020). Social STEAM learning at an early age with robotic platforms: A case study in four schools in Spain. *Sensors*, *20*(13), 3698.

Kajita, S., Hirukawa, H., Harada, K., & Yokoi, K. (2014). *Introduction to humanoid robotics* (Vol. 101). Berlin, Heidelberg: Springer.

Kambur, E. (2021). Emotional intelligence or artificial intelligence?: Emotional artificial intelligence. *Florya Chronicles of Political Economy*, *7*(2), 147-168.

Kolb, D. A. (2014). *Experiential learning: Experience as the source of learning and development*. FT Press.

Kolb, D. A., Rubin, I. M., & McIntyre, J. M. (1984). *Organizational psychology: Readings on human behavior in organizations*. Englewood Cliffs, NJ: Prentice-Hall.

Kucuk, S., & Sisman, B. (2020). Students' attitudes towards robotics and STEM: Differences based on gender and robotics experience. *International Journal of Child-Computer Interaction*, *23*, 100167.

Kumar, H., & Martin, A. (2023). Artificial emotional intelligence: Conventional and deep learning approach. *Expert Systems with Applications*, *212*, 118651.

Larkin, T. L. (2015, September). Creativity in STEM education: Reshaping the creative project. In *2015 international conference on interactive collaborative learning (ICL)* (pp. 1184-1189). IEEE.

Leavy, A., Dick, L., Meletiou-Mavrotheris, M., Paparistodemou, E., & Stylianou, E. (2023). The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature. *Journal of Computer Assisted Learning*, *39*(4), 1061-1082.

Levesque, H., & Lakemeyer, G. (2008). Cognitive robotics. *Foundations of Artificial Intelligence*, *3*, 869-886.

Liao, C. (2016). From interdisciplinary to transdisciplinary: An arts-integrated approach to STEAM education. *International Journal of Education & the Arts*, 17(36), 1-23.

Long, N. T., Yen, N. T. H., & Van Hanh, N. (2020). The role of experiential learning and engineering design process in K-12 STEM education. *International Journal of Education and Practice*, *8*(4), 720-732.

Lynch, C. R. (2021). Artificial emotional intelligence and the intimate politics of robotic sociality. *Space and Polity*, *25*(2), 184-201.

Marcos-Pablos, S., & García-Peñalvo, F. J. (2022). Emotional intelligence in robotics: A scoping review. In *New trends in disruptive technologies, tech ethics and artificial intelligence: The DITTET collection* (Vol 1., pp. 66-75). Springer International Publishing.

Matthews, G., Hancock, P. A., Lin, J., Panganiban, A. R., Reinerman-Jones, L. E., Szalma, J. L., & Wohleber, R. W. (2021). Evolution and revolution: Personality research for the coming world of robots, artificial intelligence, and autonomous systems. *Personality and Individual Differences*, *169*, 109969.

Melweth, H. M. A., Al Mdawi, A. M. M., Alkahtani, A. S., & Badawy, W. B. M. (2023). The role of artificial intelligence technologies in enhancing education and fostering emotional intelligence for academic success. *Migration Letters*, *20*(S9), 863-874.

Mhlanga, D. (2022). The fourth industrial revolution: An introduction to its main elements. In *Digital financial inclusion: Revisiting poverty theories in the context of the fourth industrial revolution* (pp. 17-38). Cham: Springer International Publishing.

Miglino, O., Lund, H. H., & Cardaci, M. (1999). Robotics as an educational tool. *Journal of Interactive Learning Research*, *10*(1), 25-47.

Mohr-Schroeder, M. J., Cavalcanti, M., & Blyman, K. (2015). STEM education: Understanding the changing landscape. In *A practice-based model of STEM teaching* (pp. 3-14). Brill.

Narimisaei, J., Naeim, M., Imannezhad, S., Samian, P., & Sobhani, M. (2024). Exploring emotional intelligence in artificial intelligence systems: a comprehensive analysis of emotion recognition and response mechanisms. *Annals of Medicine and Surgery*, *86*(8), 4657-4663.

Noble, S. M., Mende, M., Grewal, D., & Parasuraman, A. (2022). The fifth industrial revolution: How harmonious human–machine collaboration is triggering a retail and service [r] evolution. *Journal of Retailing*, *98*(2), 199-208.

Papadakis, S., Vaiopoulou, J., Sifaki, E., Stamovlasis, D., & Kalogiannakis, M. (2021). Attitudes towards the use of educational robotics: Exploring pre-service and in-service early childhood teacher profiles. *Education Sciences*, *11*(5), 204.

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity, 31*, 31-43.

Piaget, J. (1972). *The psychology of the child*. New York: Basic Books.

Remington, T. F., Chou, P., & Topa, B. (2023). Experiential learning through STEM: Recent initiatives in the United States. *International Journal of Training and Development*, *27*(3-4), 327-359.

Ren, M., Chen, N., & Qiu, H. (2023). Human-machine collaborative decision-making: An evolutionary roadmap based on cognitive intelligence. *International Journal of Social Robotics*, *15*(7), 1101-1114.

Ribeiro, J., Lima, R., Eckhardt, T., & Paiva, S. (2021). Robotic process automation and artificial intelligence in industry 4.0–a literature review. *Procedia Computer Science*, *181*, 51-58.

Rifandi, R., & Rahmi, Y. L. (2019). STEM education to fulfill the 21st century demand: A literature review. In *Journal of Physics: Conference Series,1317*(1), 012208. IOP Publishing.

Safrudin, F. M., Budiyanto, C. W., & Yuana, R. A. (2021, March). The influence of educational robotics to abstraction skill in high school. In *Journal of Physics: Conference Series*, 1808(1), 012018. IOP Publishing.

Salas-Pilco, S. Z. (2020). The impact of AI and robotics on physical, social-emotional and intellectual learning outcomes: An integrated analytical framework. *British Journal of Educational Technology*, *51*(5), 1808-1825.

Saleem, A., Kausar, H., & Deeba, F. (2021). Social constructivism: A new paradigm in teaching and learning environment. *Perennial journal of history*, *2*(2), 403-421.

Seyitoğlu, F., & Ivanov, S. (2024). Robots and emotional intelligence: A thematic analysis. *Technology in Society*, *77*, 102512.

Sisman, B., Kucuk, S., & Yaman, Y. (2021). The effects of robotics training on children's spatial ability and attitude toward STEM. *International Journal of Social Robotics*, *13*(2), 379-389.

Soori, M., Arezoo, B., & Dastres, R. (2023). Artificial intelligence, machine learning and deep learning in advanced robotics, a review. *Cognitive Robotics*,*3*,54-70.

Tinmaz, H. (2020). History of industrial revolutions: From homo sapiens hunters to bitcoin hunters. In *Blockchain technology for industry 4.0: Secure, decentralized, distributed and trusted industry environment* (pp.1-26).

Tselegkaridis, S., & Sapounidis, T. (2021). Simulators in educational robotics: A review. *Education Sciences*, *11*(1), 11.

Tselegkaridis, S., & Sapounidis, T. (2022). Exploring the features of educational robotics and STEM research in primary education: A systematic literature review. *Education Sciences*, *12*(5), 305.

Uslu, N., Yavuz, G. O., & Kocak- Usluel, Y. (2023). A systematic review study on educational robotics and robots. *Interactive Learning Environments*, *31*(9), 5874-5898.

Vicente, F. R., Zapatera Llinares, A., & Montes Sanchez, N. (2021). Curriculum analysis and design, implementation, and validation of a STEAM project through educational robotics in primary education. *Computer Applications in Engineering Education*, *29*(1), 160-174.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

White, D. W. (2014). What is STEM education and why is it important. *Florida Association of Teacher Educators Journal*, *1*(14), 1-9.

Widya, Rifandi, R., & Rahmi, Y. L. (2019). STEM education to fulfil the 21st century demand: A literature review. *Journal of Physics: Conference Series*, *1317*(1), 012208.

Yang, Y.-T. C., Chen, Y.-C., & Hung, H.-T. (2022). Digital storytelling as an interdisciplinary project to improve students' English speaking and creative thinking. *Computer Assisted Language Learning*, *35*(4), 840-862.

Zeng, R., Wen, Y., Zhao, W., & Liu, Y. J. (2020). View planning in robot active vision: A survey of systems, algorithms, and applications. *Computational Visual Media, 6*, 225-245.

Zhu, L., & Atompag, S. M. (2023). The application of the constructivism theory in enhancing classroom teaching. *Journal of Contemporary Educational Research, 7*(12), 209–211.

Zviel-Girshin, R., Luria, A., & Shaham, C. (2020). Robotics as a tool to enhance technological thinking in early childhood. *Journal of Science Education and Technology*, *29*(2), 294-302.

Author Information

Christopher Dignam
Governors State University
1 University Parkway, University Park, Illinois 60484
United States
Contact e-mail: *cdignam@govst.edu*
ORCID iD: https://orcid.org/0009-0007-3185-4825

Candace M. Smith
Governors State University
1 University Parkway, University Park, Illinois 60484
United States
ORCID iD: https://orcid.org/0009-0006-2545-6479

Amy L. Kelly
Governors State University
1 University Parkway, University Park, Illinois 60484
United States
ORCID iD: https://orcid.org/0009-0002-2972-8655