A Survey of Engineering Education and Literacy in K-12 STEM Curriculum Development

www.surveyx.cn

Abstract

This survey paper explores the integration of engineering education and literacy within K-12 STEM curricula, emphasizing the transition from traditional to contemporary educational methodologies. The paper investigates the effectiveness of project-based learning (PBL) and its impact on student engagement and learning outcomes, highlighting successful case studies and programs. It examines the integration of engineering principles and literacy, focusing on pedagogical strategies and the role of technology in enhancing learning experiences. The survey addresses challenges in curriculum development, emphasizing the need for equity and access, and explores interdisciplinary approaches to real-world problem-solving. The paper also delves into the significance of ethical and critical thinking skills in STEM education. Future research directions are identified, including the need for empirical validation of integrated STEM frameworks, the development of scalable models of Education 4.0, and the integration of AI education into core curricula. By addressing these research gaps, the paper contributes to the ongoing discourse on enhancing STEM education, ultimately bridging the gap between educational theory and practical application in K-12 settings.

1 Introduction

1.1 Importance of Engineering Education in K-12

Engineering education is integral to the K-12 framework, enabling students to engage with STEM disciplines through hands-on learning experiences. By embedding engineering principles into the curriculum, students can connect theoretical knowledge with practical application, thereby enhancing problem-solving abilities and addressing real-world challenges [1]. This method not only deepens understanding of scientific and mathematical concepts but also overcomes the limitations of traditional education by fostering innovative pedagogical strategies [2].

The incorporation of computational thinking and coding into K-12 curricula is particularly vital, as it transitions from rote mastery of computational logic to a more experiential approach, cultivating critical and creative thinking skills necessary for navigating a rapidly changing technological landscape [2]. Recent empirical studies highlight the transformative potential of AI technologies in STEM education, showcasing AI-STEM initiatives that enhance educational outcomes and prepare students for future advancements [3].

Vocational education complements engineering education by aligning with industrial needs, particularly within economic communities like the ASEAN Economic Community (AEC), producing graduates equipped with relevant workforce skills [4]. This alignment underscores the role of engineering education in developing a skilled workforce that contributes to national development and societal wellbeing [5].

Moreover, project-based learning (PBL) enriches engineering education by fostering active engagement and collaboration among students. PBL's documented effectiveness in K-12 settings allows

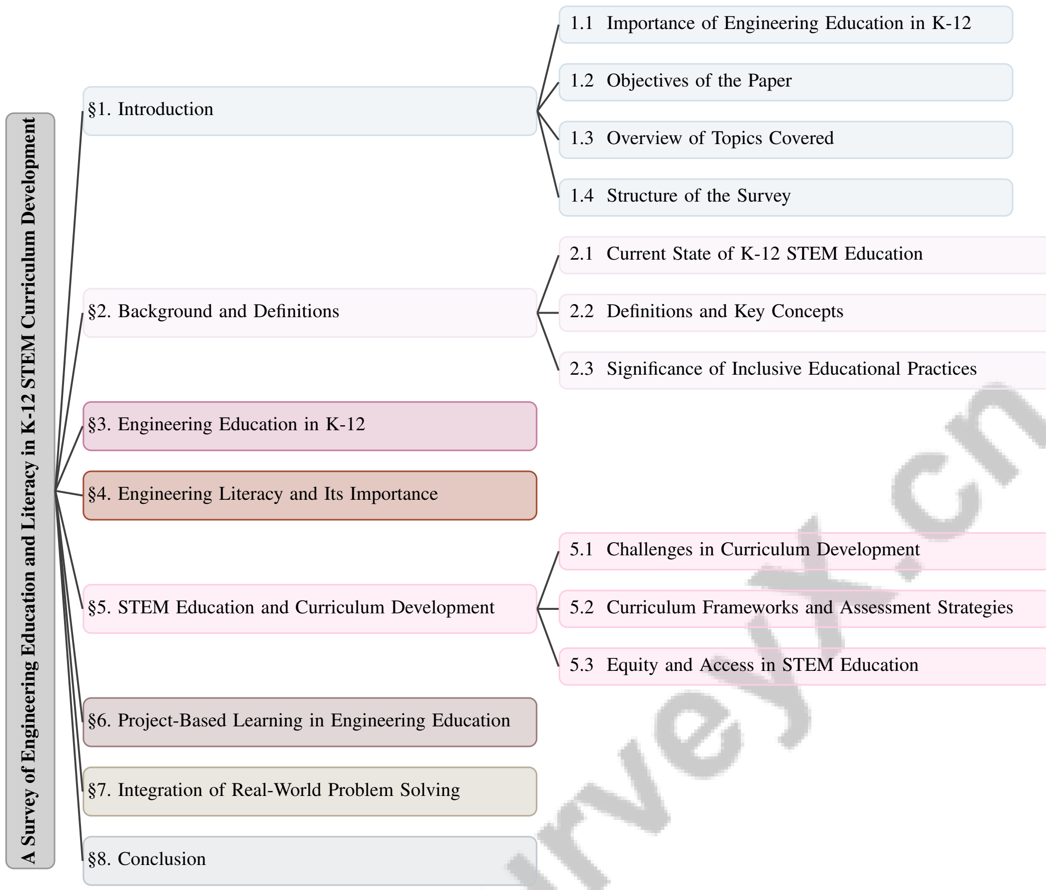

Figure 1: chapter structure

students to apply knowledge in meaningful contexts [6]. Through this inclusive and dynamic learning environment, engineering education prepares students for academic and professional success while empowering them to become informed citizens in an increasingly complex world.

1.2 Objectives of the Paper

This paper aims to investigate the integration of engineering education and literacy within K-12 STEM curricula, focusing on enhancing computational thinking and literacy through age-appropriate programming tools that engage young learners with technology [7]. A key objective is to establish a structured approach to prompt engineering that improves user interactions with AI language models, thereby fostering critical thinking and problem-solving skills among students. By addressing gaps in AI literacy among K-12 educators and students, the paper seeks to dispel misconceptions and enhance understanding through structured educational interventions, including the development of an app incorporating goal-based scenarios and project-based learning [8].

Additionally, the paper examines integrated learning frameworks, such as Sheridan's Integrated Learning Block (ILB), to enhance engineering education and address curriculum design challenges [9]. It synthesizes research on gamification in K-12 education, proposing a framework for developing effective gamified learning environments that boost student engagement and learning outcomes [10].

The application of AI tools like ChatGPT as co-advisors in elementary school science fair projects within PBL contexts is also explored, assessing their impact on educational experiences and outcomes [11]. Furthermore, the paper discusses the necessity of adapting engineering education to meet Industry 4.0 demands, ensuring students are prepared for future technological advancements [12].

The importance of repeated interventions over one-off experiences in fostering STEM aspirations among students is emphasized [13]. By leveraging manga as a communication medium, the paper aims to facilitate better understanding and collaboration among interdisciplinary teams in the Requirements

Development process [14]. Additionally, the survey informs MIT's New Engineering Education Transformation (NEET) by evaluating the global state of engineering undergraduate education and identifying current and emerging leaders in the field [15].

Finally, the paper investigates factors influencing student retention in STEM fields post-graduation, focusing on disparities based on individual characteristics and institutional experiences [16]. It addresses the challenge of integrating diverse AI techniques into STEM education to enhance instructional quality [3]. Through these objectives, the paper contributes to the ongoing discourse on enhancing STEM education, bridging the gap between educational theory and practical application in K-12 settings, while identifying common themes and providing valuable insights for researchers and stakeholders [17].

1.3 Overview of Topics Covered

This survey paper comprehensively addresses the integration of engineering education and literacy within K-12 STEM curricula, emphasizing the shift from traditional to contemporary educational methodologies. A significant focus is placed on incorporating aesthetic experiences into computing education, highlighting the challenges of making these experiences relevant to students' lives [7]. The paper evaluates innovative pedagogical models such as blended learning, which combines rotational and flexible non-rotational models to integrate physical and virtual learning environments, enhancing data literacy in science education [18].

The effectiveness of the ActiveAI program in promoting AI literacy among students is also explored, providing insights that guide future improvements in AI education [8]. The role of ChatGPT as a co-advisor in PBL contexts is examined, demonstrating its potential to facilitate educational processes and enhance student engagement [11].

Empirical studies on gamification are reviewed, focusing on individual and environmental factors, learning processes, and outcomes within K-12 education [10]. The paper discusses storytelling-based workshops that integrate robotics and maker skills to promote environmental literacy among middle school students, illustrating the intersection of technology and environmental education [19].

The integration of engineering practices within STEM education, particularly for secondary education teachers, is examined to understand the practical applications of engineering concepts in classroom settings [20]. Through these discussions, the paper aims to provide a holistic understanding of current trends, challenges, and strategies in advancing engineering education and literacy within K-12 STEM curricula.

1.4 Structure of the Survey

This survey paper is organized into several key sections addressing the integration of engineering education and literacy within K-12 STEM curricula. It begins with an introduction that highlights the importance of engineering education in K-12 settings and outlines the primary objectives and topics covered. The subsequent section provides a comprehensive background on the current state of K-12 STEM education, defining essential concepts such as engineering education, literacy, and project-based learning, while emphasizing the significance of inclusive educational practices.

Core sections delve into the integration of engineering principles within K-12 curricula, examining their impact on student learning and showcasing successful case studies. The concept of engineering literacy is explored, discussing pedagogical strategies and the role of technology in enhancing literacy. The relationship between STEM education and curriculum development is scrutinized, focusing on challenges, curriculum frameworks, and ensuring equity and access.

Project-based learning is analyzed for its effectiveness in teaching engineering concepts, supported by examples of hands-on activities and the integration of participatory design and AI systems. The survey highlights the critical role of real-world problem-solving in K-12 education by examining strategies for integrating practical applications into the curriculum, enhancing students' ethical reasoning and critical thinking skills. This approach aligns with the growing emphasis on STEM education, advocating for interdisciplinary connections and innovative instructional practices that engage students in addressing real-world challenges, ultimately preparing them for future societal complexities [21, 22, 23, 24].

The paper concludes with a summary of key findings, reflections on the integration of engineering education into K-12 curricula, and recommendations for future research. The structure also incorporates discussions on the PySTEMM method, experimental evaluations, and conclusions drawn from these findings, providing a comprehensive framework for understanding and advancing engineering education in K-12 settings [25].The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Current State of K-12 STEM Education

K-12 STEM education faces numerous challenges and opportunities driven by evolving educational demands and technological advancements. Early STEM integration is crucial for developing problem-solving and critical thinking skills, yet many curricula, particularly in fields like telecommunication engineering, remain outdated, hindering students' preparation for modern technological and industry needs [26]. The ineffective implementation of technology in education, where ICT is underutilized, exacerbates this issue [27]. The U.S. faces a STEM workforce shortage, reflected in unfilled engineering roles and low STEM graduation rates [28], while ambiguities in STEM education definitions further complicate its effective implementation [17].

The varied interpretations of STEM education impede strategy development, particularly in environmental science, where rote learning limits engagement and critical thinking [19]. The absence of frameworks for emerging technologies like 3D modeling presents additional challenges, necessitating innovative teaching adaptations [29]. Efforts to integrate computational thinking in K-12 curricula often overlook the complexity of learner experiences, underscoring the need for a holistic educational approach [2].

Innovative pedagogies like blended learning and gamification show promise in enhancing engagement and outcomes. Blended learning, which merges physical and virtual settings, improves data literacy among teachers and students [18], while programs using authentic research experiences, such as those with astronomical data, offer valuable hands-on learning [30]. The limited impact of one-off STEM activities highlights the necessity for sustained interventions to significantly influence student aspirations and educational paths. Comprehensive strategies are essential to ensure STEM education is accessible, equitable, and prepares students for a rapidly changing world. The integration of engineering practices in secondary education remains insufficient, requiring better teacher preparation and support [20]. Current research often focuses on higher education, potentially neglecting AI's applicability in lower educational levels [3].

2.2 Definitions and Key Concepts

In K-12, engineering education is an interdisciplinary method emphasizing design, implementation, and operational thinking to enhance problem-solving skills [26]. It integrates social, cultural, and historical contexts, enabling practical application of engineering principles [31]. Engineering literacy expands this, addressing societal challenges and fostering informed citizenship [32].

Project-Based Learning (PBL) is a student-centered approach where learning occurs through projects addressing real-world problems, promoting collaboration and engagement [33]. The PjBL model, a structured PBL variant, enhances competencies through active learning [4], though challenges like teacher resistance and PBL's inherent ambiguity persist [6].

Computational thinking is experiential and discursive, integrating computer science to foster creativity and innovation in engineering education [2, 34]. Challenges include teachers' lack of confidence in engineering concepts and systemic barriers like time constraints [20].

The survey introduces a holistic framework based on General System Theory (GST), categorizing AI-STEM research into elements like subject, information, and technology [3]. AI integration in K-12 education offers opportunities and challenges, particularly in teacher knowledge and training [35]. Insufficient data literacy training among teachers limits instructional improvement [18].

Integrating engineering education, literacy, and project-based learning in K-12 curricula is crucial for preparing students for a technologically advanced world. The broad definitions and interpretations of STEM education highlight implementation challenges across educational levels [17].

2.3 Significance of Inclusive Educational Practices

Inclusive STEM educational practices are essential for engaging all students, regardless of background or abilities, in science, technology, engineering, and mathematics. Challenges include the lack of consensus on STEM literacy definitions, complicating the establishment of a unified educational framework [36]. The complexities of visual perception and the need for instructional designers to adapt to evolving technologies further complicate inclusivity [37].

Integrating computer science and computational thinking into curricula is crucial for inclusivity, yet barriers persist due to definitional disagreements [38]. Providing accessible resources and teacher support is vital for adopting new methodologies and effectively using technology in project-based learning [39]. Teacher training and institutional support are critical for adopting innovative practices like flipped classrooms, enhancing engagement and outcomes [40].

Challenges such as inadequate AI technology training for educators and ethical implications of AI use present hurdles [24]. Effective AI tool integration in collaborative learning is necessary to address concerns about AI-generated information accuracy and potential reductions in human interaction [41]. Resistance to change within educational institutions, often slow to adapt to new technologies and methodologies, is a significant barrier to inclusivity [12].

Institutional constraints and the lack of consensus on STEM content and practices hinder interdisciplinary approaches essential for inclusivity [22]. Limited AI knowledge among teachers and the need for training underscore the importance of inclusive practices [35]. Prioritizing inclusivity can make STEM education more equitable, equipping students to navigate and contribute to an increasingly complex technological world.

In recent years, the integration of engineering education into K-12 curricula has gained significant attention, as it plays a crucial role in fostering students' interest in STEM fields. This integration not only enhances the learning experience but also equips students with essential skills for the future. To illustrate this hierarchical structure, Figure 2 provides a comprehensive overview of how engineering principles can be effectively incorporated into educational frameworks. This figure highlights the integration of engineering principles, its impact on student learning, and successful case studies and programs. Furthermore, it emphasizes key pedagogical frameworks, teaching approaches, learning outcomes, technological tools, and innovative programs that collectively contribute to enhancing STEM education. By visualizing these components, the figure serves as a valuable resource for educators and policymakers aiming to implement effective engineering education strategies in K-12 settings.

3 Engineering Education in K-12

3.1 Integration of Engineering Principles

Integrating engineering principles into K-12 curricula is vital for preparing students to thrive in a technologically advanced world. This integration requires adopting pedagogical frameworks that emphasize personalized, project-based, and interdisciplinary learning, aligning with Education 4.0 objectives [5]. These methods enhance understanding by connecting engineering concepts to real-world applications and promoting active student engagement.

Project-based learning (PBL) is a key strategy, combining design principles, instructional strategies, and assessment methods to boost student engagement and comprehension of scientific concepts. PBL's emphasis on real-world problem-solving fosters critical thinking, enabling students to apply knowledge in meaningful contexts, thus enhancing problem-solving skills and scientific literacy within a STEM framework [1].

Incorporating phenomenological perspectives in teaching computational thinking emphasizes experiential processes over technical skills [2]. This approach deepens engagement by situating engineering principles within lived experiences, fostering a holistic understanding of STEM concepts.

Moreover, integrating AI competencies into the curriculum involves categorizing methods like learning prediction, intelligent tutoring systems, and educational robots [3]. These categories underscore AI's growing educational significance and the need for educators to effectively implement AI principles.

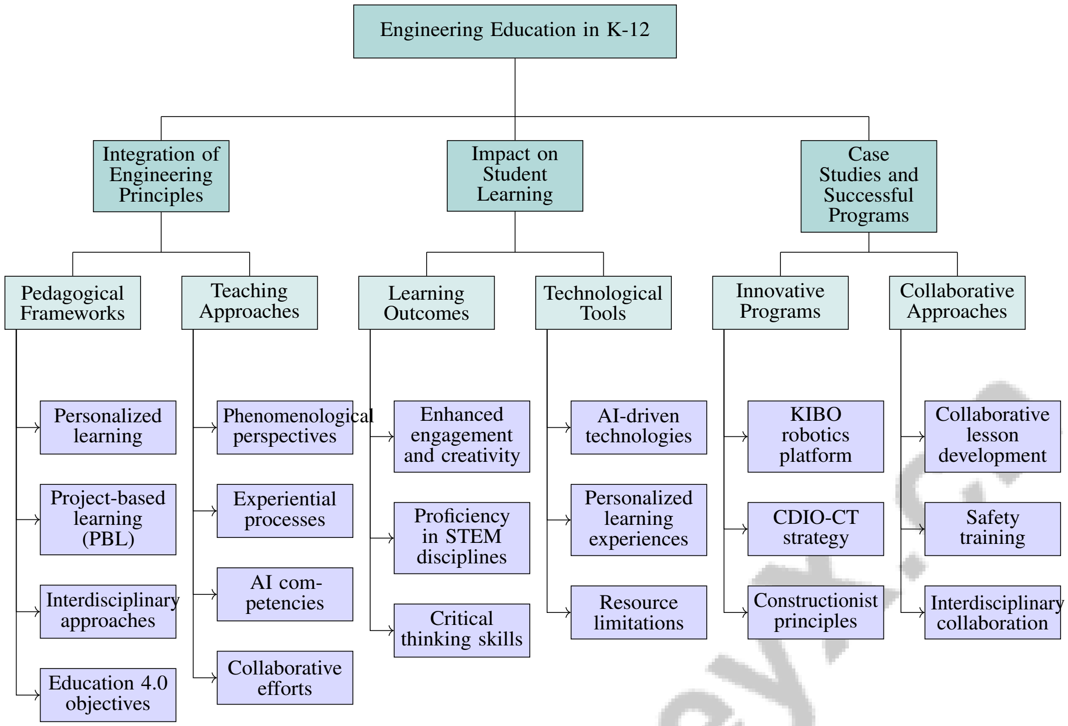

Figure 2: This figure illustrates the hierarchical structure of integrating engineering education into K-12 curricula, highlighting the integration of engineering principles, its impact on student learning, and successful case studies and programs. The figure emphasizes key pedagogical frameworks, teaching approaches, learning outcomes, technological tools, and innovative programs that contribute to enhancing STEM education.

Ultimately, embedding engineering principles in K-12 curricula demands innovative pedagogical strategies, supportive educational ecosystems, and a focus on real-world applications. Recent research highlights collaborative efforts that create dynamic learning environments, equipping students with essential skills to navigate contemporary complexities. By employing frameworks that enhance active learning and promote information literacy through prompt engineering, educators can foster critical thinking and discipline fluency, preparing students for the challenges posed by technological advancements and information management [42, 43].

3.2 Impact on Student Learning

Integrating engineering education in K-12 curricula significantly enhances student learning outcomes by promoting engagement, creativity, and proficiency in STEM disciplines. Central to this impact is project-based learning (PBL), which provides hands-on experiences that deepen understanding and retention of complex concepts [6]. PBL engages students with real-world problems, fostering creativity and critical thinking skills essential for contemporary challenges.

As illustrated in Figure 3, key strategies and tools for enhancing student learning in K-12 engineering education include pedagogical strategies, technological tools, and teacher development, all of which are pivotal elements in this educational framework. Self-efficacy is crucial for scientific literacy; students with high self-efficacy demonstrate superior literacy skills compared to peers with lower self-efficacy [1]. This underscores the importance of cultivating confidence and motivation in students to maximize engineering education benefits. Additionally, professional development for teachers is vital, enhancing their confidence and ability to integrate engineering principles, positively influencing student outcomes [20].

Technological tools, especially AI-driven technologies, play a crucial role in personalizing learning experiences and addressing diverse student needs. These tools promote inclusivity and offer advantages like tailored learning experiences and administrative time savings [35]. However, effective use

AI-generated, for reference only.

of AI tools like ChatGPT in engineering education requires expert knowledge due to limitations in accuracy and reliability [44].

Addressing resource limitations and developing guidelines tailored to K-12 learners' developmental stages is essential for successfully integrating engineering education [30]. Overcoming these challenges enables educators to better meet young learners' needs, ensuring they are prepared for future challenges.

Integrating engineering education, supported by innovative pedagogical strategies such as problem-centered and inquiry-based learning, along with advanced technological tools like AI and prompt engineering, is pivotal in enhancing student engagement and learning outcomes in STEM fields. This multifaceted approach cultivates critical thinking and creativity, preparing students to tackle contemporary societal challenges, contributing to a more skilled and diverse STEM workforce [24, 45, 46, 47, 48].

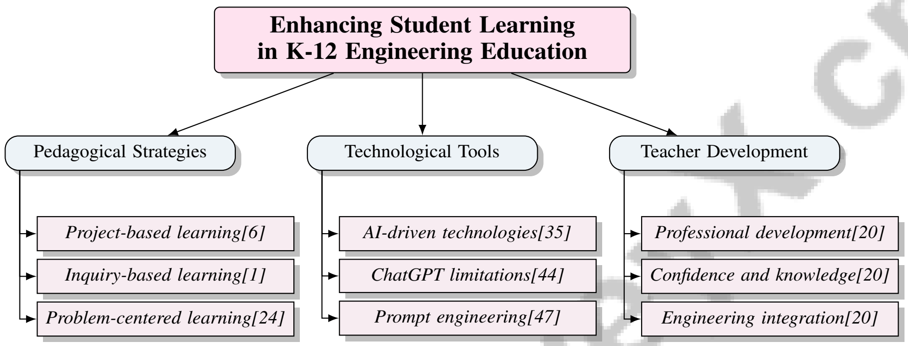

Figure 3: This figure illustrates key strategies and tools for enhancing student learning in K-12 engineering education, highlighting pedagogical strategies, technological tools, and teacher development as pivotal elements.

3.3 Case Studies and Successful Programs

Successful integration of engineering education into K-12 curricula is illustrated by various programs showcasing innovative teaching methodologies and collaborative approaches. Case-based learning in compiler design, for instance, significantly improves student engagement and understanding by applying theoretical concepts to practical scenarios, enhancing problem-solving skills [49].

The KIBO robotics platform, implemented in over 500 schools worldwide, exemplifies another successful initiative. KIBO's constructionist approach fosters creativity and problem-solving, engaging students with engineering concepts through hands-on, interactive learning experiences [50]. This program demonstrates the effectiveness of tangible, real-world applications in engineering education.

The collaborative CDIO-CT strategy successfully integrates engineering principles with computational thinking to solve complex problems, like determining a mathematical pendulum's period, promoting interdisciplinary learning and collaboration [51]. Such initiatives highlight engineering education's potential to enhance students' analytical and critical thinking abilities.

Additionally, applying constructionist principles in robotics education significantly boosts creativity and problem-solving skills. This approach emphasizes hands-on learning and knowledge construction through active engagement with technological tools [52]. By fostering an exploratory environment, these programs deepen students' understanding of engineering concepts.

Collaborative lesson development programs involving teachers and network scientists have proven more effective than traditional methods. This collaboration facilitates resource sharing and expertise, resulting in dynamic educational experiences for students [39]. Such initiatives underscore the value of interdisciplinary collaboration in enhancing engineering education quality.

Furthermore, a study on K-12 educators teaching design-based technology and engineering concepts revealed insights into safety training experiences. Comparing data from northeastern educators with those from other regions underscores the importance of safety training in engineering education, ensuring students engage in projects within secure environments [53].

Lastly, a case study involving a summer course for fifth-grade students used agent-based modeling software and musical programming to democratize computation learning. This program demonstrates the potential of integrating engineering education with creative disciplines, broadening student engagement and understanding of computational and engineering concepts [7].

Collectively, these case studies and educational programs highlight innovative strategies for integrating engineering education into K-12 curricula. They emphasize enhancing student learning outcomes and fostering critical sociotechnical literacy. By leveraging diverse histories and ways of knowing, these initiatives prepare students to navigate future challenges in a rapidly evolving technological landscape, ultimately aiming to create equitable learning environments resonating with students' everyday experiences and community contexts [45, 46, 54, 47, 48].

4 Engineering Literacy and Its Importance

4.1 Defining Engineering Literacy

Engineering literacy involves a comprehensive understanding of engineering principles, emphasizing critical thinking, problem-solving, and interdisciplinary engagement with real-world systems. It extends beyond technical knowledge, fostering informed citizenship and decision-making [32]. Educational frameworks that integrate real-world challenges and deliberate practice are crucial for developing engineering literacy, enabling students to acquire essential skills regardless of their previous academic backgrounds [32]. Project-Based Learning (PBL) and tools like ScratchJr and KIBO promote creativity, collaboration, and practical application of theoretical knowledge, while gamification enhances learning outcomes [6, 10].

Engineering literacy also requires technological integration, particularly AI frameworks, to enhance information literacy and critical thinking. Developing AI literacy is vital for navigating educational complexities, highlighting the need for curricula tailored to address K-12 gaps [24, 30]. Reframing computational thinking as an experiential process is essential, incorporating both embodied and computational modeling [2]. Enhancing self-efficacy correlates with improved scientific literacy and learning outcomes [1]. Teachers' pedagogical self-efficacy and awareness of engineering careers are critical for promoting engineering literacy [20].

Incorporating storytelling and robotics can effectively enhance environmental literacy, engaging students in meaningful exploration of environmental issues [19]. Tools like ChatGPT enrich learning by providing personalized feedback, though challenges in integration persist. A well-defined STEM education framework emphasizing problem-centered, inquiry-based, design-based, and cooperative learning cultivates diverse skills, preparing students for complex challenges in a technology-driven society. These interdisciplinary strategies enhance cognitive and affective learning outcomes, equipping students for future workforce demands [34, 45, 55, 24].

4.2 Pedagogical Strategies for Developing Engineering Literacy

Developing engineering literacy requires diverse pedagogical strategies focused on hands-on learning, real-world applications, and technology integration. As illustrated in Figure 4, which emphasizes pedagogical strategies for enhancing engineering literacy, each category highlights specific methods and frameworks that contribute to developing comprehensive engineering education. Project-Based Learning (PBL) engages students in real-world projects, deepening their understanding of engineering concepts and enhancing motivation [7, 12]. Incorporating Large Language Models (LLMs) like ChatGPT into PBL frameworks fosters creativity and personalized feedback, enhancing engagement [56, 46]. GenAIbots further promote personalized learning, critical thinking, and collaborative discussions [41].

Integrating real-world applications and teamwork in educational programs is essential for fostering engineering literacy. Hands-on programs promote peer learning and collaboration, crucial for developing practical skills [12]. The WoT4EDP framework exemplifies integrating multiple ways of thinking, fostering deeper student engagement [57]. As educators engage with AI technologies, recognizing their benefits and ethical dilemmas is imperative, with future research focusing on ethical AI use, innovative assessment methods, and equitable access [21, 58]. Prompt engineering can moderately improve AI performance, highlighting the need for educators to critically evaluate and integrate these technologies [59].

By implementing diverse strategies that foster sociotechnical and AI literacy, educators can significantly enhance engineering literacy. This equips students with skills to navigate technology-society-environment relationships, preparing them for meaningful engagement in a complex world. These strategies encourage connecting engineering concepts to everyday experiences, promoting equitable participation and understanding of societal engineering impacts [36, 24, 42, 46, 48].

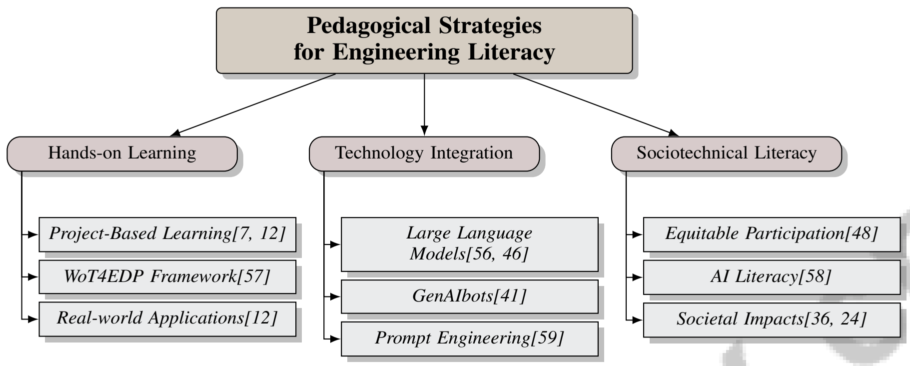

Figure 4: This figure illustrates pedagogical strategies for enhancing engineering literacy, emphasizing hands-on learning, technology integration, and sociotechnical literacy. Each category highlights specific methods and frameworks that contribute to developing comprehensive engineering education.

4.3 Role of Technology in Enhancing Engineering Literacy

Advancements in technology are crucial for enhancing engineering literacy by providing innovative tools and platforms for interactive learning. Mixed Reality (MR) environments offer immersive experiences that significantly enhance understanding of engineering concepts, with future research needed on intuitive development, interdisciplinary applications, and technical challenges [60]. Incorporating AI technologies offers substantial opportunities for personalized learning and critical thinking development, adapting to individual needs and fostering comprehensive understanding [61, 46, 48, 55, 62].

The use of Large Language Models (LLMs) like ChatGPT illustrates technology's transformative potential in enhancing literacy. These models personalize educational content, promote creativity, and provide tailored feedback, facilitating collaborative activities that nurture critical thinking [46, 63]. Integrating technology within PBL frameworks enhances engagement and understanding by facilitating collaboration, fostering critical thinking, and enabling self-directed exploration of real-world problems [64, 65]. This approach supports skill development crucial for addressing technological challenges.

Strategic use of technology enhances engineering literacy, equipping students with skills for success in a rapidly evolving landscape. By addressing technological challenges, particularly AI, and leveraging their potential, educational systems create enriched learning experiences accommodating diverse needs, including underrepresented STEM groups, while equipping students with AI literacy, prompt engineering, and critical thinking skills [61, 24].

5 STEM Education and Curriculum Development

Category	Feature	Method
Challenges in Curriculum Development	Blended Learning Approaches	STEM-PBL-GI[1], PBL-4S[66]
Curriculum Frameworks and Assessment Strategies	Curriculum Design and Alignment	CM[67]

Table 1: This table summarizes the methods used to address challenges in curriculum development and the frameworks and assessment strategies in STEM education. It highlights blended learning approaches and curriculum design techniques, referencing specific methodologies such as STEM-PBL-GI and PBL-4S, alongside curriculum mapping strategies.

STEM (Science, Technology, Engineering, and Mathematics) education is increasingly vital due to evolving educational demands, supported by enhanced public funding and institutional backing. This

AI-generated, for reference only.

emphasis underscores the importance of STEM in fostering problem-solving skills and scientific literacy, aligning with broader educational research to improve STEM implementation [17, 31]. Addressing the multifaceted challenges in curriculum development is crucial for creating effective learning environments. Table 1 provides a concise summary of the methods employed to tackle challenges in curriculum development and the strategies for curriculum frameworks and assessment in STEM education. The following discussion focuses on specific obstacles in curriculum development that impede successful STEM initiatives in K-12 education, highlighting the need for inclusive and engaging curricula and examining frameworks and assessment strategies to enhance STEM education.

5.1 Challenges in Curriculum Development

Developing K-12 STEM curricula involves overcoming systemic and pedagogical challenges. A significant issue is the technocentric focus of current educational practices, which often emphasize computational abstractions over experiential learning, potentially reducing student engagement and understanding of STEM concepts [2]. Blended learning offers a promising approach to boost engagement and adapt teaching through real-time data [18], yet its implementation requires understanding its interaction with students' self-efficacy [1].

Figure 5 illustrates the primary challenges in developing K-12 STEM curricula, focusing on technocentric educational practices, the role of blended learning, and systemic barriers affecting teacher development and AI literacy. Integrating engineering practices into curricula faces systemic barriers affecting teacher development and initiative sustainability [20], including inconsistent implementation, lack of standardized PBL definitions, and assessment challenges [6]. Selecting appropriate AI techniques for STEM education also presents challenges [3], with AI literacy integration constrained by resources and alignment with educational goals.

Variations in student engagement and motivation further complicate STEM curricula success [5], while securing stakeholder investment in real-world projects remains a barrier [66]. Addressing these challenges—ensuring equitable access, integrating disciplines, and maintaining curricular integrity—requires collaboration among educators, researchers, and policymakers to develop adaptable, inclusive STEM curricula reflecting diverse educational contexts and innovative practices [22, 68, 69, 70].

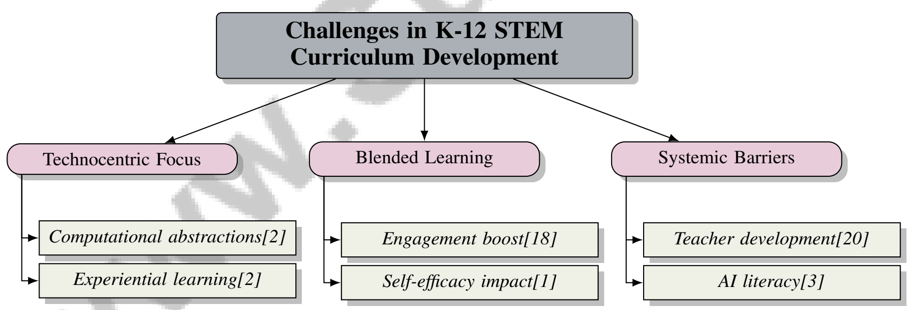

Figure 5: This figure illustrates the primary challenges in developing K-12 STEM curricula, focusing on technocentric educational practices, the role of blended learning, and systemic barriers affecting teacher development and AI literacy.

5.2 Curriculum Frameworks and Assessment Strategies

Developing curriculum frameworks and assessment strategies in STEM education is crucial for meeting educational goals and evaluating outcomes. Viewing curriculum as praxis integrates learning processes, aims, and content, fostering a holistic development approach [75]. Curriculum mapping systematically represents program plans, aiding stakeholders in educational decision-making [67]. Table 2 presents a comprehensive summary of benchmarks relevant to the discussion on curriculum frameworks and assessment strategies in STEM education.

Incorporating computational thinking (CT) across disciplines is essential in modern STEM curricula. By categorizing CT research and practices, educators can structure approaches to enhance problem-solving skills and interdisciplinary understanding [38]. Frameworks classifying assessments by disciplinary nature and objectives further support this integration [70].

Benchmark	Size	Domain	Task Format	Metric
MPL[71]	33	Electrical Engineering	Project-based Learning	Chi-square, T-test
PL-LLM[63]	23	Educational Science	Text Personalization	Mann-Whitney U Test
RATsApp[72]	1,000	Mathematical Literacy	Formative Assessment	Perceived Usefulness, Output Quality
DSAScratch[73]	10	Computer Science Education	User Study	Quiz Scores, Survey Responses
ChatGPT-Physics[59]	40	Physics	Problem Solving	Accuracy
TEE-Safety[53]	191	Technology And Engineering Education	Safety Assessment	Accident Occurrences, Safety Training Completion
CSIBI[74]	303	Computer Science Education	Self-report Survey	Confirmatory Factor Analysis, Structural Equation Modeling

Table 2: This table provides an overview of various benchmarks utilized in STEM education research, highlighting their respective sizes, domains, task formats, and evaluation metrics. These benchmarks serve as examples of diverse educational settings and assessment methodologies, underscoring the importance of tailored evaluation strategies in curriculum development.

The 'Backward Design with Pre-/Post-Quizzes' method ensures assessments align with learning goals from the outset, contrasting traditional approaches [76]. Formative assessment instruments are vital for evaluating students' modeling processes, providing feedback for instructional adjustments [77]. Blended learning models, combining physical and virtual environments, facilitate active learning and engagement, offering flexibility for diverse learners while maintaining rigorous standards [18].

Collaborative curriculum development and teaching strategies enhance STEM education by fostering environments for sharing insights and resources, improving practices and outcomes [78]. A change model incorporating multiple perspectives and emphasizing cultural transformation alongside practical improvements can inform STEM curriculum assessment strategies [79].

5.3 Equity and Access in STEM Education

Ensuring equity and access in STEM education involves addressing systemic barriers and fostering inclusive learning environments. Integrating socio-scientific issues into curricula enhances engagement and empowers students to apply learning to real-world challenges, promoting responsible citizenship and meaningful STEM engagement [80].

Systemic barriers, including oppression and cultural stereotypes, marginalize minoritized groups, limiting STEM access [81]. Addressing these challenges requires policies and practices supporting diverse learners [68], including accommodations for students with specific needs like ADHD [82].

Shifting engineering education towards experiential and participatory learning enhances equity and access [48]. Pedagogical strategies emphasizing active learning and real-world applications create inclusive environments accommodating diverse learning styles and needs.

Coherent STEM policies are essential to support under-represented groups and ensure accessible education [5]. Public funding and collaborative research efforts advance these policies, preventing socio-economic factors from hindering quality STEM education access [31].

Conceptual frameworks clarifying STEM and technology education relationships enhance curriculum development and outcomes [83]. Future improvements should focus on better teacher training and simplifying curriculum implementation to support equitable access [75].

6 Project-Based Learning in Engineering Education

6.1 Effectiveness of Project-Based Learning

Project-Based Learning (PBL) is a transformative pedagogical strategy that integrates theoretical knowledge with practical application through real-world projects, thereby enhancing critical thinking, problem-solving, and collaboration skills vital for engineering and STEM fields [84]. Hands-on projects, such as those in redesigned telecommunication engineering courses, significantly boost student engagement and comprehension [26]. The interdisciplinary nature of PBL, exemplified by the use of manga techniques to improve communication between users and engineers, enhances understanding of complex engineering concepts [14]. Furthermore, PBL increases motivation and self-efficacy across various contexts, including engineering and language learning [85].

Innovative tools like 3D modeling within PBL frameworks further enhance engagement and understanding, surpassing traditional methods [29]. The integration of real-world applications fosters technical skills and critical thinking [4]. Future research should focus on refining PBL definitions and design principles, alongside enhancing teacher training and support mechanisms to optimize its effectiveness [6]. PBL has been shown to improve student learning and stakeholder satisfaction by enhancing engagement and providing real-world experience [66].

As illustrated in Figure 6, PBL's effectiveness is further emphasized by categorizing its enhancement areas, innovative tools, and future research directions. This figure highlights the critical aspects of PBL, including its impact on critical thinking, student engagement, interdisciplinary learning, and the integration of real-world applications. PBL's effectiveness in engineering education lies in its ability to create dynamic, interdisciplinary learning environments that develop technical and collaborative skills within multidisciplinary teams. Real-world challenges across fields like Computer Science, Electrical Engineering, and Applied Physics foster critical thinking and effective communication. Surveys indicate that 70% of students felt better prepared for multidisciplinary teamwork after PBL experiences compared to traditional methods [64, 54, 86]. Such environments equip students to navigate the complexities of a technological world, preparing them for future professional and academic challenges.

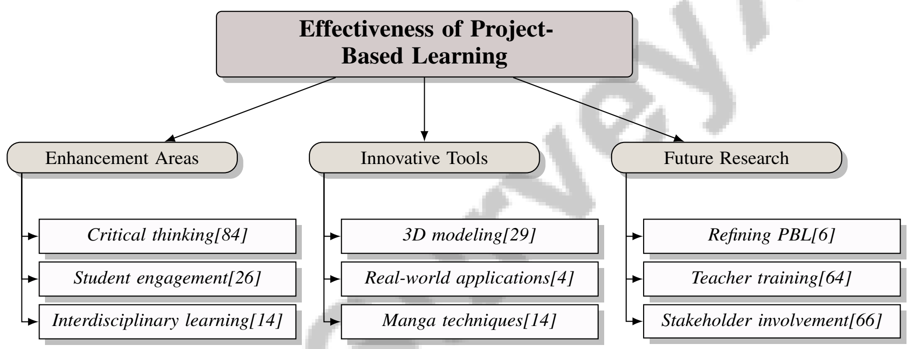

Figure 6: This figure illustrates the effectiveness of Project-Based Learning (PBL) by categorizing its enhancement areas, innovative tools, and future research directions, emphasizing critical thinking, student engagement, interdisciplinary learning, and the integration of real-world applications.

6.2 Project-Based and Hands-On Learning Approaches

Project-Based Learning (PBL) and hands-on approaches create dynamic educational environments emphasizing student-centered, collaborative experiences. These methods focus on real-world relevance and student-driven inquiry, enabling engagement in complex tasks that develop problem-solving, decision-making, and independent work capabilities [84]. Activities like designing robotic manipulators enhance understanding of interdisciplinary collaboration and system integration, crucial in modern engineering education [49].

Using tools like KIBO's wooden blocks for building robots and ScratchJr for interactive storytelling fosters creativity and problem-solving skills [50]. Integrating AI tools like ChatGPT as educational co-advisors expands student and teacher capabilities, promoting personalized learning and critical thinking [11]. Workshops on AI scenario speculation illustrate PBL's potential in enhancing engagement with complex concepts [56].

The structured PBL approach, comprising seven steps from understanding learning outcomes to presenting results, ensures active student involvement, enhancing engagement and comprehension [4]. Interdisciplinary collaboration among educational programs allows students from diverse backgrounds to work on real projects, fostering teamwork and communication skills [66].

By prioritizing active participation and practical applications, PBL and hands-on methodologies empower students with essential skills for thriving in a technology-driven landscape. These approaches facilitate interdisciplinary collaboration, as evidenced by projects integrating Computer Science, Electrical Engineering, and Applied Physics, enabling students to tackle real-world challenges. Research indicates that such immersive experiences enhance critical thinking and problem-solving abilities, improving students' capacity for multidisciplinary teamwork and surpassing traditional methods in engagement and learning outcomes [34, 64, 54, 86, 65].

6.3 Participatory Design and AI Systems

Participatory design in project-based learning (PBL) fosters collaboration and student engagement by actively involving learners in the process, deepening their understanding of engineering concepts and their real-world applications [87]. Technology integration in PBL, such as with MEShaT, enhances participatory experiences by improving coordination between tutors and students, leading to effective learning outcomes.

AI plays an increasingly prominent role in participatory design, offering avenues for personalized learning and real-time feedback, thus fostering an interactive and engaging environment [85]. Involving external stakeholders in academic projects presents students with real-world challenges, enriching their learning experiences and enhancing problem-solving skills [66].

Future research should focus on comprehensive teacher training in data literacy and exploring emerging technologies like generative AI in blended learning environments. These initiatives can enhance participatory design in PBL by equipping educators with skills and tools to facilitate dynamic and engaging learning experiences [18].

7 Integration of Real-World Problem Solving

7.1 Integrating Real-World Applications

Incorporating real-world applications into educational curricula is essential for connecting theoretical knowledge with practical problem-solving, thereby enhancing student engagement and competence. Case studies, such as the mathematical pendulum, demonstrate how theoretical concepts can be applied to real-world challenges, fostering deeper understanding through meaningful exploration [51]. The Project-Based Learning (PjBL) model further supports this integration by promoting student ownership through engagement with real-world issues, thereby enhancing problem-solving skills, critical thinking, and creativity [4]. These methods highlight the importance of real-world applications in education, linking academic concepts with practical experiences and motivating students to pursue STEM fields. For instance, insights from text mining in engineering programs reveal that personal motivations, influenced by gender and socio-economic factors, significantly shape students' interest in technology and social impact. Innovative instructional strategies, such as Fluency-Inspiring Questions and Student Representation Tasks, aim to enhance discipline fluency, while leveraging social media to connect students with diverse STEM role models can further inspire interest and career aspirations. Additionally, understanding youths' everyday knowledge of machine learning through a knowledge-in-pieces perspective emphasizes the need for educational tools that build on existing knowledge to improve AI literacy [61, 43, 28, 23]. Such approaches create dynamic learning environments that equip students with the skills and knowledge necessary to address future challenges effectively.

7.2 Ethical and Critical Thinking in Real-World Contexts

Cultivating ethical and critical thinking skills is fundamental for real-world problem-solving in education, enabling students to navigate complex ethical dilemmas and make informed decisions in a rapidly evolving technological landscape. Integrating real-world applications and ethical considerations into the curriculum enhances students' capacity to tackle complex challenges, aligning with contemporary educational frameworks that emphasize collaborative input from diverse stakeholders [21, 43, 88, 67]. Project-Based Learning (PBL) frameworks effectively develop these skills by engaging students in real-world projects that necessitate ethical considerations and informed decision-making [87]. Immersing students in authentic scenarios encourages exploration of ethical dimensions, fostering a deeper understanding of the consequences of their actions. The integration of artificial intelligence (AI) technologies into educational contexts presents unique opportunities for enhancing ethical and critical thinking skills. AI-driven tools provide real-time feedback, allowing students to evaluate their understanding and approach to problem-solving while raising ethical concerns regarding data privacy, bias, and diminished human interaction [85, 24]. Interdisciplinary approaches that emphasize understanding the broader social and cultural contexts of technological advancements further support the incorporation of ethical considerations into STEM education [31]. Engaging students in discussions that highlight the ethical dimensions of scientific and technological developments fosters a holistic understanding of their societal impact.

7.3 Interdisciplinary and Multidisciplinary Approaches

Interdisciplinary and multidisciplinary approaches are crucial for addressing complex real-world problems, as they integrate diverse perspectives and expertise from various fields, leading to comprehensive understanding and innovative solutions [31]. In STEM education, these methods encourage students to synthesize knowledge and skills from multiple domains, promoting a holistic approach to problem-solving. An example of integrating interdisciplinary approaches in education is the collaborative CDIO-CT strategy, which merges engineering principles with computational thinking to tackle complex problems, such as determining the period of a mathematical pendulum [51]. This strategy not only enhances analytical and critical thinking abilities but also showcases the potential of interdisciplinary collaboration in solving challenging real-world issues. Incorporating interdisciplinary methods within project-based learning (PBL) frameworks allows students to engage with real-world applications that necessitate knowledge integration from various fields. By addressing actual challenges faced in diverse industries, students develop a deeper understanding of the interconnectedness among disciplines and the significance of collaboration in resolving complex issues [4]. The use of technology, such as artificial intelligence (AI), further bolsters interdisciplinary and multidisciplinary approaches by providing tools that facilitate collaboration and enhance problem-solving capabilities. AI-driven technologies offer personalized learning experiences and real-time feedback, enabling students to engage more effectively with interdisciplinary projects and develop the skills necessary to navigate complex challenges [85].

8 Conclusion

8.1 Future Directions and Research Gaps

Advancing K-12 engineering education necessitates a comprehensive exploration of educational frameworks that align with evolving workforce requirements, emphasizing the integration of new technologies and systems thinking. Expanding Project-Based Learning (PBL) methodologies to encompass a broader range of courses is essential for enhancing student outcomes. Research should focus on embedding AI tools within authentic PBL settings, leveraging educators' insights to refine assessment strategies. Validating integrated STEM education frameworks through empirical studies is crucial, with attention to their impact on learning and success factors. Collaborative approaches to STEM engagement, involving diverse stakeholders and considering the broader learning ecology, are vital for fostering foundational skills in subjects like trigonometry and algebra. Investigating the applicability of technology-enabled methods across educational contexts and exploring the teaching of creativity components independently is necessary. Further research should delve into the use of manga techniques in software development and their effect on team dynamics. Longitudinal studies are needed to establish causality and evaluate comprehensive student experiences, alongside effective career service interventions in STEM fields. Developing scalable Education 4.0 models and strategies to overcome institutional resistance to change are critical. Future research should prioritize integrating innovative practices at scale, addressing large cohort teaching challenges, and exploring online learning potential. Establishing frameworks for collaborative sensemaking among educators and innovative STEM education integration approaches in diverse contexts are imperative. Additionally, integrating AI education into core curricula, enhancing teacher training, and ensuring equitable AI literacy access are essential priorities. Targeted educator training programs to improve AI understanding and application, alongside pedagogical frameworks incorporating computational thinking as a STEM language, should be central objectives.

References

[1] Hana Lestari and Ima Rahmawati. Integrated stem through project based learning and guided inquiry on scientific literacy abilities in terms of self-efficacy levels. *Al Ibtida: Jurnal Pendidikan Guru MI*, 7(1):19–32, 2020.

[2] Pratim Sengupta, Amanda Dickes, and Amy Farris. Toward a phenomenology of computational thinking in stem education, 2018.

[3] Weiqi Xu and Fan Ouyang. The application of ai technologies in stem education: a systematic review from 2011 to 2021. *International Journal of STEM Education*, 9(1):59, 2022.

[4] Nizwardi Jalinus, Rahmat Azis Nabawi, and Aznil Mardin. The seven steps of project based learning model to enhance productive competences of vocational students. In *International Conference on Technology and Vocational Teachers (ICTVT 2017)*, pages 251–256. Atlantis Press, 2017.

[5] Brigid Freeman, Simon Marginson, and Russell Tytler. An international view of stem education. In *STEM Education 2.0*, pages 350–363. Brill, 2019.

[6] Barbara Condliffe. Project-based learning: A literature review. working paper. *MDRC*, 2017.

[7] Amy Farris and Pratim Sengupta. Democratizing children's computation: Learning computational science as aesthetic experience, 2015.

[8] Ying Jui Tseng and Gautam Yadav. Activeai: Introducing ai literacy for middle school learners with goal-based scenario learning, 2023.

[9] Mouhamed Abdulla, Meagan Troop, and Amjed Majeed. Framework for an integrated learning block with cdio-led engineering education, 2020.

[10] Hojjat Dehghanzadeh, Mohammadreza Farrokhnia, Hossein Dehghanzadeh, Kiumars Taghipour, and Omid Noroozi. Using gamification to support learning in k-12 education: A systematic literature review. *British Journal of Educational Technology*, 55(1):34–70, 2024.

[11] Fabiano Villan and Renato P. dos Santos. Chatgpt as co-advisor in scientific initiation: Action research with project-based learning in elementary education, 2023.

[12] Shuvra Das, Darrell K Kleinke, and David Pistrui. Reimagining engineering education: Does industry 4.0 need education 4.0? In *2020 ASEE Virtual Annual Conference Content Access*, 2020.

[13] Martin Archer, Jennifer DeWitt, Carol Davenport, Olivia Keenan, Lorraine Coghill, Anna Christodoulou, Samantha Durbin, Heather Campbell, and Lewis Hou. Going beyond the one-off: How can stem engagement programmes with young people have real lasting impact?, 2020.

[14] Yasushi Tanaka, Hajimu Iida, and Yasuhiro Takemura. A manga-driven system requirements development pbl exercise, 2018.

[15] Ruth Graham. The global state of the art in engineering education. *Massachusetts Institute of Technology (MIT) Report, Massachusetts, USA*, 2018.

[16] Linli Zhou, Damji Heo Stratton, and Xin Li. Retention in stem: Factors influencing student persistence and employment, 2024.

[17] Key definitions of stem educatio.

[18] Jozef Hanč, Dominik Borovský, and Martina Hančová. Blended learning: A data-literate science teacher is a better teacher, 2024.

[19] Mukil M. V., Gayathri Manikutty, Divya Vijayan, Aparna Rangudu, and Bhavani Rao R. When elephants nodded and dolls spoke: Bringing together robotics and storytelling for environmental literacy, 2022.

[20] Ngss-based teacher professional.

[21] Selin Akgun and Christine Greenhow. Artificial intelligence in education: Addressing ethical challenges in k-12 settings. *AI and Ethics*, 2(3):431–440, 2022.

[22] Tamara D Holmlund, Kristin Lesseig, and David Slavit. Making sense of “stem education” in k-12 contexts. *International journal of STEM education*, 5:1–18, 2018.

[23] Luis Morales-Navarro and Yasmin B. Kafai. Investigating youths’ everyday understanding of machine learning applications: a knowledge-in-pieces perspective, 2024.

[24] Yoshija Walter. Embracing the future of artificial intelligence in the classroom: the relevance of ai literacy, prompt engineering, and critical thinking in modern education. *International Journal of Educational Technology in Higher Education*, 21(1):15, 2024.

[25] Kelsey D’Souza. Pystemm: Executable concept modeling for k-12 stem learning, 2014.

[26] Mouhamed Abdulla, Zohreh Motamedi, and Amjed Majeed. Redesigning telecommunication engineering courses with cdio geared for polytechnic education, 2019.

[27] Mar Pérez-Sanagustín, Miguel Nussbaum, Isabel Hilliger, Carlos Alario-Hoyos, Rachelle S Heller, Peter Twining, and Chin-Chung Tsai. Research on ict in k-12 schools–a review of experimental and survey-based studies in computers & education 2011 to 2015, 2017.

[28] Ling He, Lee Murphy, and Jiebo Luo. Using social media to promote stem education: Matching college students with role models, 2016.

[29] Tânia Rocha, Ana Ribeiro, Joana Oliveira, Ricardo Nunes, Diana Carvalho, Hugo Paredes, and Paulo Martins. 3d modelling to address pandemic challenges: A project-based learning methodology, 2024.

[30] Xiaofei Zhou, Jessica Van Brummelen, and Phoebe Lin. Designing ai learning experiences for k-12: Emerging works, future opportunities and a design framework, 2020.

[31] Yeping Li, Ke Wang, Yu Xiao, and Jeffrey E Froyd. Research and trends in stem education: A systematic review of journal publications. *International journal of STEM education*, 7:1–16, 2020.

[32] Eric Burkholder, Shima Salehi, Sarah Sackeyfio, Nicel Mohamed-Hinds, and Carl Wieman. An equitable and effective approach to introductory mechanics, 2021.

[33] L. M. Rebull. Authentic research in the classroom for teachers and students, 2018.

[34] Nesra Yannier, Scott E Hudson, Kenneth R Koedinger, Kathy Hirsh-Pasek, Roberta Michnick Golinkoff, Yuko Munakata, Sabine Doebel, Daniel L Schwartz, Louis Deslauriers, Logan McCarty, et al. Active learning:“hands-on” meets “minds-on”. *Science*, 374(6563):26–30, 2021.

[35] Irene-Angelica Chounta, Emanuele Bardone, Aet Raudsep, and Margus Pedaste. Exploring teachers’ perceptions of artificial intelligence as a tool to support their practice in estonian k-12 education. *International journal of artificial intelligence in education*, 32(3):725–755, 2022.

[36] Kok-Sing Tang and P John Williams. Stem literacy or literacies? examining the empirical basis of these constructs. *Review of Education*, 7(3):675–697, 2019.

[37] Zafer Güney. Visual literacy and visualization in instructional design and technology for learning environments. *European Journal of Contemporary Education*, 8(1):103–117, 2019.

[38] James Lockwood and Aidan Mooney. Computational thinking in education: Where does it fit? a systematic literary review, 2017.

[39] Emma K. Towlson, Lori Sheetz, Ralucca Gera, Jon Roginski, Catherine Cramer, Stephen Uzzo, and Hiroki Sayama. Nice teacher workshop: Engaging k-12 teachers in the development of curricular materials that utilize complex networks concepts, 2018.

[40] Chung Kwan Lo and Khe Foon Hew. A critical review of flipped classroom challenges in k-12 education: Possible solutions and recommendations for future research. *Research and practice in technology enhanced learning*, 12:1–22, 2017.

[41] Marco Antonio Rodrigues Vasconcelos and Renato P. dos Santos. Enhancing stem learning with chatgpt and bing chat as objects to think with: A case study, 2023.

[42] Leo S Lo. The clear path: A framework for enhancing information literacy through prompt engineering. *The Journal of Academic Librarianship*, 49(4):102720, 2023.

[43] Rica Sirbaugh French and Edward E. Prather. From a systematic investigation of faculty-produced think-pair-share questions to frameworks for characterizing and developing fluency-inspiring activities, 2020.

[44] Matthew Frenkel and Hebah Emara. Chatgpt mechanical engineering: Examining performance on the fe mechanical engineering and undergraduate exams, 2023.

[45] Lieve Thibaut, Stijn Ceuppens, Haydée De Loof, Jolien De Meester, Leen Goovaerts, Annemie Struyf, Jelle Boeve-de Pauw, Wim Dehaene, Johan Deprez, Mieke De Cock, et al. Integrated stem education: A systematic review of instructional practices in secondary education. *European Journal of STEM Education*, 3(1):2, 2018.

[46] F. V. Kowalski, S. E. Kowalski, P. B. Kohl, and V. H. Kuo. Technology-enabled nurturing of creativity and innovation: A specific illustration from an undergraduate engineering physics course, 2013.

[47] Eason Chen, Danyang Wang, Luyi Xu, Chen Cao, Xiao Fang, and Jionghao Lin. A systematic review on prompt engineering in large language models for k-12 stem education, 2024.

[48] Veronica Cassone McGowan and Philip Bell. Engineering education as the development of critical sociotechnical literacy. *Science & Education*, 29(4):981–1005, 2020.

[49] Divya Kundra and Ashish Sureka. Application of case-based teaching and learning in compiler design course, 2016.

[50] Marina Umaschi Bers. Coding, playgrounds and literacy in early childhood education: The development of kibo robotics and scratchjr. In *2018 IEEE global engineering education conference (EDUCON)*, pages 2094–2102. IEEE, 2018.

[51] Hong-Yan Zhang, Yu Zhou, Yu-Tao Li, Fu-Yun Li, and Yong-Hui Jiang. Cdio-ct collaborative strategy for solving complex stem problems in system modeling and simulation: an illustration of solving the period of mathematical pendulum, 2023.

[52] Pavel Petrovič and Fedir Agarshev. Spike up prime interest in science and technology through constructionist games, 2024.

[53] Tyler S Love, Mark D Threeton, and Kenneth R Roy. A safety study on educators of technological and engineering design-based instruction in k-12 stem related courses. *Journal of Technology Education*, 35(1):32–52, 2023.

[54] Robert Margolies, Maria Gorlatova, John Sarik, Peter Kinget, Ioannis Kymissis, and Gil Zussman. Project-based learning within a large-scale interdisciplinary research effort, 2014.

[55] Farida Selim. Connecting science fundamentals and career proficiency – development of multi-disciplinary science curriculum, 2021.

[56] Chengbo Zheng, Kangyu Yuan, Bingcan Guo, Reza Hadi Mogavi, Zhenhui Peng, Shuai Ma, and Xiaojuan Ma. Charting the future of ai in project-based learning: A co-design exploration with students, 2024.

[57] Walther Neuper. Technologies for "complete, transparent interactive models of math" in education, 2019.

[58] Junaid Qadir. Engineering education in the era of chatgpt: Promise and pitfalls of generative ai for education. In *2023 IEEE global engineering education conference (EDUCON)*, pages 1–9. IEEE, 2023.

[59] Karen D. Wang, Eric Burkholder, Carl Wieman, Shima Salehi, and Nick Haber. Examining the potential and pitfalls of chatgpt in science and engineering problem-solving, 2023.

[60] Nikolaos Pellas, Ioannis Kazanidis, and George Palaigeorgiou. A systematic literature review of mixed reality environments in k-12 education. *Education and Information Technologies*, 25(4):2481–2520, 2020.

[61] Bo Lin, Bissan Ghaddar, and Ada Hurst. Text mining undergraduate engineering programs' applications: the role of gender, nationality, and socio-economic status, 2022.

[62] Selim Coskun, Yasanur Kayikci, and Eray Gencay. Adapting engineering education to industrie 4.0 vision, 2017.

[63] Michael Vaccaro Jr au2, Mikayla Friday, and Arash Zaghi. Evaluating the capability of large language models to personalize science texts for diverse middle-school-age learners, 2024.

[64] Hamdi Serin. Project based learning in mathematics context. *International Journal of Social Sciences & Educational Studies*, 5(3):232–236, 2019.

[65] James Taylor. Study on the best uses of technology in support of project-based learning, 2017.

[66] Leonardo Humberto Silva, Renata Xavier Castro, and Marice Costa Guimaraes. Supporting real demands in software engineering with a four steps project-based learning approach, 2021.

[67] Broader terms curriculum mapping: Using natural language processing and visual-supported communication to create representative program planning experiences.

[68] Lyn D English. Advancing elementary and middle school stem education. *International Journal of Science and Mathematics Education*, 15:5–24, 2017.

[69] Esperanza Moreno, Piyush Kumar, Richard O Adansi, Dorothy Moreno, Demy Rodriguez, Raul Baez Ramirez, Audrey R Kapsa, Arturo Rodriguez, Neelam Agarwal, Vinod Kumar, Beverley A Calvo, and Vivek Tandon. Empowering abilities: Increasing representation of students with disabilities in the stem field, 2024.

[70] Xiaoyi Gao, Peishan Li, Ji Shen, and Huifang Sun. Reviewing assessment of student learning in interdisciplinary stem education. *International Journal of STEM Education*, 7:1–14, 2020.

[71] Amith Khandakar, Muhammad E. H. Chowdhury, Md. Saifuddin Khalid, and Nizar Zorba. Case study of innovative teaching practices and their impact for electrical engineering courses during covid-19 pandemic, 2021.

[72] Steffen Steinert, Lars Krupp, Karina E. Avila, Anke S. Janssen, Verena Ruf, David Dzsotjan, Christian De Schryver, Jakob Karolus, Stefan Ruzika, Karen Joisten, Paul Lukowicz, Jochen Kuhn, Norbert Wehn, and Stefan Küchemann. Lessons learned from designing an open-source automated feedback system for stem education, 2024.

[73] Ashwin Jagadeesha, Pranathi Rayavaram, Justin Marward, Sashank Narain, and Claire Seungeun Lee. Integrating data structures and algorithms in k-12 education using block-based programming, 2023.

[74] Luis Morales-Navarro, Michael T. Giang, Deborah A. Fields, and Yasmin B. Kafai. Connecting beliefs, mindsets, anxiety, and self-efficacy in computer science learning: An instrument for capturing secondary school students' self-beliefs, 2023.

[75] Dyah Tri Palupi. What type of curriculum development models do we follow? an indonesiaâ€™ s 2013 curriculum case. *Indonesian journal of curriculum and educational technology studies*, 6(2):98–105, 2018.

[76] Kathy L. Cooksey and Patrik Jonsson. Using pre-/post-quizzes intentionally in curriculum development and evaluation, 2022.

[77] Mei-Hung Chiu and Jing-Wen Lin. Modeling competence in science education. *Disciplinary and Interdisciplinary Science Education Research*, 1(1):12, 2019.

[78] John G Wells. Stem education: The potential of technology education. 2019.

[79] Daniel L. Reinholz, Joel C. Corbo, Melissa H. Dancy, Noah Finkelstein, and Stanley Deetz. Towards a model of systemic change in university stem education, 2015.

[80] Katja Maass, Vince Geiger, Marta Romero Ariza, and Merrilyn Goos. The role of mathematics in interdisciplinary stem education. *Zdm*, 51:869–884, 2019.

[81] Christa Jackson, Margaret J Mohr-Schroeder, Sarah B Bush, Cathrine Maiorca, Thomas Roberts, Caitlyn Yost, and Abigail Fowler. Equity-oriented conceptual framework for k-12 stem literacy. *International Journal of STEM Education*, 8:1–16, 2021.

[82] Caroline Bustamante, Erin Scanlon, and Jacquelyn J. Chini. Supporting students with adhd in introductory physics courses: Four steps for instructors, 2021.

[83] Chikahiko Yata, Tadashi Ohtani, and Masataka Isobe. Conceptual framework of stem based on japanese subject principles. *International Journal of STEM Education*, 7:1–10, 2020.

[84] Oktay Kızkapan and Oktay Bektaş. The effect of project based learning on seventh grade students' academic achievement. 2017.

[85] Myeong-Hee Shin. Effects of project-based learning on students' motivation and self-efficacy. *English teaching*, 73(1):95–114, 2018.

[86] Ciptro Handrianto and Muhammad Arinal Rahman. Project based learning: a review of literature on its outcomes and implementation issues. *LET: Linguistics, Literature and English Teaching Journal*, 8(2):110–129, 2018.

[87] Danco Davcev, Biljana Stojkoska, Slobodan Kalajdziski, and Kire Trivodaliev. Project based learning of embedded systems, 2017.

[88] Diego Ortega-Auquilla, Irma Fajardo-Pacheco, Johanna Cabrera-Vintimilla, and Paul Siguenza-Garzón. A comprehensive overview on the fundamentals of curriculum development: understanding key interrelated theoretical aspects. *Revista Boletín Redipe*, 8(11):148–168, 2019.

Disclaimer:

SurveyX is an AI-powered system designed to automate the generation of surveys. While it aims to produce high-quality, coherent, and comprehensive surveys with accurate citations, the final output is derived from the AI's synthesis of pre-processed materials, which may contain limitations or inaccuracies. As such, the generated content should not be used for academic publication or formal submissions and must be independently reviewed and verified. The developers of SurveyX do not assume responsibility for any errors or consequences arising from the use of the generated surveys.

AI-generated, for reference only.