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Article

The Era of Intelligence: The Picture and Path of STEM Education to Empower the Cultivation of New Quality Talents

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Abstract: The cultivation of new quality talents has become a strategic need for national development. STEM education and intelligent technology are crucial in fostering the high-quality development of these talents. However, effectively integrating intelligent technology with STEM education to enhance students 'comprehensive abilities is a significant challenge for educators. This paper explores how STEM education can empower the development of new quality talents in the digital intelligence era, delves into the essence of interdisciplinary integration driven by intelligent technology, and provides an in-depth analysis of the development landscape and implementation paths of intelligent technology in STEM education. The study finds that intelligent technology can significantly boost students' interest in learning, innovation capabilities, and problem-solving skills. However, it also highlights issues such as inadequate top-level design, teacher professional development, evaluation system improvement, and data security protection. Based on these findings, the paper proposes targeted strategies to provide more effective practical pathways for the interdisciplinary integration of STEM education.

Keywords: stem education; new quality talents; intelligent technology

1. Introduction

The cultivation of new quality talents has become a strategic need for national development, with STEM education and intelligent technology serving as key pathways to foster high-quality new quality talents. The integration of intelligent technology with STEM is a significant trend in the education sector, gradually permeating all aspects of teaching, learning, management, research, and evaluation. With the rapid advancement of science and technology, the rise of intelligent technology has not only transformed traditional teaching methods but also presented unprecedented opportunities and challenges for STEM education. In 2015, the Ministry of Education outlined in the 'Guidelines on Comprehensively Promoting the Deepening of Educational Informatization during the 13th Five-Year Plan Period (Draft for Comments)' the exploration of new educational models such as STEM education and maker education (Bao Lei, 2021). In September 2023, President Xi Jinping emphasized, 'Integrate scientific and technological innovation resources to lead the development of strategic emerging industries and future industries, accelerating the formation of new quality productive forces' (Chang Chengming, 2020). The development of new quality productive forces requires the cultivation of new quality talents who can fully utilize new quality production tools and generate innovative production value. New quality talents are the primary and decisive factors in the formation of new quality productive forces (Zhu Zhiting, Dai Ling, et al., 2024). Wu Jiang pointed out that talents engaged in high-level, high-difficulty, complex, and innovative labor play a more significant role in the formation of new quality productive forces (Wu Jiang & Feng Dingguo, 2024). Therefore, the cultivation of new quality talents is a crucial component in building a strong educational nation.

2. The Connotation Analysis of STEM Interdisciplinary Integration

2.1. Definition and Characteristics of Stem Education

STEM stands for Science, Technology, Engineering, and Mathematics. Originating in the United States, STEM education integrates these four disciplines into a comprehensive interdisciplinary approach. It covers almost all areas related to science, technology, engineering, and mathematics, including psychology, economics, sociology, and more, forming a multidisciplinary field with a strong emphasis on science and engineering (Yang Yaping, 2015). The goal of STEM education is to cultivate innovative talents (Feng Hua, 2016). The integration of STEM education theory with subject disciplines, students 'problem-solving abilities, and the development of their core competencies indicates that higher levels of subject integration lead to stronger problem-solving skills and better core competency development. The A-STEM theory includes the intensity of humanistic guidance, the degree of subject reconstruction and integration, and the effectiveness of cultivating students' humanistic spirit. It suggests that greater humanistic guidance intensity, higher degree of subject reconstruction and integration, and better effects in cultivating students humanistic spirit are all positive outcomes. The project-based STEM education theory examines four dimensions: the quality of project design, the level of interdisciplinary knowledge integration, and the extent of teachers interdisciplinary integration literacy improvement. It finds that higher project design quality, higher interdisciplinary knowledge integration, and greater improvement in teachers 'interdisciplinary integration literacy are all beneficial. The local resource-based STEM education theory focuses on three aspects: the utilization of local resources, the level of curriculum innovation, and the enhancement of students' comprehensive qualities. It concludes that higher utilization of local resources, higher levels of curriculum innovation, and more significant improvements in students 'comprehensive qualities are all positive outcomes. The kindergarten STEM activity design theory combines the psychological and physical characteristics of young children, exploring the rationality of activity design, the development level of early childhood STEM literacy, and the effectiveness of teaching models. It finds that more reasonable activity design leads to higher early childhood STEM literacy development and more effective teaching models. In summary, STEM education is rich in meaning and varies across different educational stages and contexts, but ultimately serves to cultivate students' comprehensive abilities and promote their all-round development.

2.2. The Core Characteristics of New Quality Talents

The report of the 20th National Congress of the Communist Party of China (CPC) emphasizes the need to deeply implement the strategy of making the country strong through talent. Talent is the driving force behind innovation, a decisive factor in promoting high-quality development, and a key element in accelerating the formation of new productive forces. New-type talents are innovative and enduring individuals who can lead the development of new productive forces and embody the technological characteristics of the digital and intelligent era. They are also ecological builders who actively engage with complex natural and social ecosystems, integrate into the comprehensive transformation system of society, and establish their primary responsibilities. Additionally, they are technical embodiment talents who can fully utilize modern technology, adapt to advanced modern equipment, and possess the ability to rapidly update their knowledge (Zhu Zhiting, Dai Ling, et al., 2024). Guo Yifeng et al. highlight that new productive forces not only require workers to have professional knowledge and skills but also demand higher standards for their learning abilities, coordination skills, innovation capabilities, and human-machine collaboration skills (Guo Yifeng & Gao Ke, 2024). Zhu Zhiting et al. emphasize that new-type talents must understand the current state of social development and possess creative thinking, be able to integrate complex social systems and think comprehensively, and actively adapt to the development of new technologies and possess technical thinking (Zhu Zhiting, Zhao Xiaowei, et al., 2024). Therefore, new-type talents are innovative, composite, and leading figures.

2.3. Advantages of Smart Technology Enabling STEM Education

2.3.1. Smart Technology Can Help STEM Interdisciplinary Integration

Firstly, intelligent technology can facilitate the integration of STEM disciplines, offering more possibilities and convenience for this interdisciplinary approach. By utilizing technologies such as virtual reality (VR) and augmented reality (AR), students can gain a more intuitive understanding of how interdisciplinary knowledge is applied in real-world scenarios, thereby enhancing the fun and effectiveness of their learning. Additionally, intelligent technology provides a wealth of learning resources and tools, supporting students in independent exploration and collaborative learning, which promotes the integration and application of interdisciplinary knowledge. Secondly, the integration of STEM disciplines helps develop students' comprehensive qualities. STEM education emphasizes the organic integration of knowledge and skills from various fields, including science, technology, engineering, and mathematics. Through project-based learning and other methods, students are encouraged to develop interdisciplinary thinking, innovation, problem-solving, and teamwork skills while tackling real-world problems, better preparing them for the demands of future societal development.

2.3.2. STEM Education Helps to Cultivate New Quality Talents

The integration of intelligent technology with STEM is a significant trend in the education sector. STEM education emphasizes interdisciplinary integration, practical orientation, and problem-driven approaches, aligning with the intrinsic needs for cultivating new-type talents. This integration helps to nurture versatile talents who can meet the demands of future society. With the rapid advancement of technology, today's high-level knowledge and complex technical applications span multiple disciplines, requiring researchers to have interdisciplinary research capabilities and a deep understanding of intelligent technology. The application of artificial intelligence in healthcare requires professionals who are proficient in both technology and multidisciplinary knowledge, including medicine and mathematics. In robotics courses, students must not only master mechanical engineering (the E in STEM) to design robot structures but also apply computer science (the C in STEM) for programming control, use mathematical knowledge for algorithm optimization, and conduct scientific experiments to verify the rationality of their designs. In the field of intelligent manufacturing, new-type talents need to develop innovation, engineering practice, interdisciplinary integration, data analysis, and digital management skills through STEM education, mastering technologies such as artificial intelligence, big data, and the Internet of Things, and integrating them into the entire process of intelligent manufacturing optimization and innovation. In the realm of green development, STEM education, with its problem-driven and practical application characteristics, helps new-type talents form sustainable development awareness, green technology development capabilities, environmental assessment and governance capabilities, and cross-disciplinary collaboration skills, enabling them to combine ecological protection with economic development and promote green technological innovation. Furthermore, STEM education fosters strategic thinking, technical ethics, social responsibility, and a global perspective among new quality talents through project-based learning and real-world tasks. This model of STEM education shares significant commonalities: it emphasizes the systematic integration of different disciplines, the simultaneous enhancement of practical skills and innovative awareness, and the comprehensive development of teamwork and social responsibility. Ultimately, interdisciplinary STEM education driven by intelligent technology can support the cultivation of such talents. The development of these skills not only aligns with the national strategic needs for smart manufacturing and green development but also provides a scientific approach and solid foundation for the high-quality growth of new quality talents across various fields.

3. The Picture of Integrated Development of STEM Disciplines

3.1. From Single Discipline to Interdisciplinary Integration

STEM education is gradually shifting from a single-discipline teaching model to an interdisciplinary integration approach, a trend that is essential for addressing complex real-world problems and nurturing comprehensive innovative talents (English, 2016). The core of interdisciplinary integration lies in breaking down disciplinary barriers, organically integrating knowledge and skills from science, technology, engineering, and mathematics, and applying them to solve real-world problems. In project-based learning, students need to integrate knowledge from multiple disciplines to complete complex tasks, such as designing environmental protection equipment or modeling solutions to climate change (Capraro & Slough, 2013). This method not only enhances students 'ability to transfer knowledge but also fosters critical thinking and innovation, making them better prepared for the demands of future society. In the context of the core competencies era, teachers are increasingly focusing on developing students' problem-solving skills, and STEM education, as an innovative interdisciplinary approach, has gained significant attention. In 2017, Yu Xiaoya conducted practical research at key experimental schools, analyzing the theoretical basis and practical experiences and issues of interdisciplinary integration driven by STEM education, and explored the development and practice of courses aimed at cultivating interdisciplinary comprehensive talents. Early childhood STEM education has received increasing attention, with kindergarten STEM activities emphasizing interdisciplinary integration. In 2023, Wu Zhenhua studied the design of kindergarten STEM activities, noting that early childhood STEM education is valued, and kindergarten STEM activities emphasize interdisciplinary integration (Wu Zhenhua et al., 2023),

3.2. Technology-Driven Model Innovation

The rapid advancement of digital technology has provided robust support for the innovation of STEM education models. Interactive programming software and virtual reality labs are reshaping teaching practices, enabling students to engage in learning with greater immersion and practicality (Radianti et al., 2020). These technologies not only diversify learning methods but also provide teachers with tools to quantify student learning processes, supporting more precise teaching decisions. For instance, virtual labs have overcome the limitations of physical experimental equipment, offering students a repeatable and immediately feedback experimental environment, significantly enhancing the efficiency of practical teaching (Zhang & Liu, 2024). Technology-driven innovations in educational models not only enhance students 'hands-on skills and subject interest but also make it possible to promote high-quality STEM education on a large scale. As research progresses, interdisciplinary integration practices are becoming increasingly diverse. In 2022, Cao Wei noted that under the core competencies framework, STEM education, as an innovative interdisciplinary approach, has gained attention, breaking down disciplinary boundaries through project-based learning to create new forms of interdisciplinary education (Cao Wei, 2019). Zhuang Tengteng's faculty members reported that the course satisfaction of third-year and fourth-year students is significantly higher than that of first-year and second-year students, and the interdisciplinary nature of STEM courses has a stronger impact on the course satisfaction of first-year and second-year students compared to third-year and fourth-year students (Zhuang & Wang, 2021). In the same year, Gu Jian and Li Gang explored engineering-based interdisciplinary practice inspired by STEM (Gu Jian & Li Gang, 2022).

3.3. Personalization and Customization of Learning Style

Big data and artificial intelligence (AI) technologies are becoming key tools for personalizing and tailoring learning methods. In STEM education, these technologies can analyze students 'learning behaviors in real time, enabling the creation of personalized learning paths for each student. For example, adaptive learning systems can dynamically adjust the difficulty and pace of learning content based on students' knowledge levels, helping them focus on areas that best suit their development (Kabudi et al., 2021). Additionally, AI tutoring tools, through personalized recommendation mechanisms, not only significantly enhance students 'learning efficiency but also boost their interest and intrinsic motivation. Research indicates that personalized learning paths help bridge individual learning gaps and provide more flexible and scientific support for students' long-term development. Zhou Lihong explored and practiced teaching methods to address the issues in promoting STEM courses in Guangzhou, developing a 'cross-disciplinary integration' model for STEM projects (Zhou Lihong, 2022). Ye Zhenheng leveraged local resources to develop STEM education courses, proposing the concept of 'integration' and building a school-based curriculum system (Ye Zhenheng, 2022). The STEM literacy of preschool children encompasses four dimensions: knowledge integration and application at the experiential level, technical design and innovation at the tool level, scientific thinking and expression at the behavioral level, and active learning and inquiry at the attitude level. These dimensions collectively form the core competencies that support young children in conducting interdisciplinary investigative activities (Cai Meihui et al., 2023).

Overall, domestic research on STEM education exhibits characteristics of multiple stages and fields. In the early stage, the focus was on exploring theories and experiences of interdisciplinary integration practices. In the middle stage, there was diverse development across various scenarios, covering areas such as curriculum design and problem-solving. In the later stage, research delved into preschool education, conducting systematic studies on the design of STEM activities in kindergartens. Domestic research has continuously expanded and deepened from theory to practice, providing rich outcomes and references for interdisciplinary integration in the education sector. Foreign research has also gone through several stages of development, from the early theoretical foundation to subsequent development and improvement, application expansion, innovation breakthroughs, and detailed refinement, culminating in modern comprehensive development. Each stage has its unique features and contributions. The early stage focused on building foundational theories, laying the groundwork for subsequent research. The development and improvement stage further expanded and deepened these theories. The application and expansion stage emphasized applying theories to practical situations and expanding across disciplines. The innovation and breakthrough stage achieved significant theoretical and methodological innovations. The deepening and refinement stage paid more attention to details and in-depth analysis. The modern comprehensive development stage showed a trend towards interdisciplinary and global collaboration, leveraging information technology to drive innovation and transformation in research. These stages of research are interconnected and mutually reinforcing, collectively promoting the continuous development and progress of the field.

4. STEM Education Contributes to the Development Path of New Quality Talents

4.1. Strengthen Top-Level Design and Improve Institutions and Mechanisms

Amid the digital wave, the rapid advancement of intelligent technology facilitates the integration and cross-disciplinary collaboration among different fields, breaking down disciplinary barriers and fostering students' comprehensive qualities and innovative capabilities. First, improving policy support and management mechanisms is crucial for the sustainable development of STEM education. This involves strengthening top-level design at both national and local levels. The education department should establish a clear policy framework that outlines the goals, tasks, curriculum standards, and evaluation systems for STEM education across different educational stages. For instance, it should accurately define the characteristics of each stage of education and set clear phased training objectives. It should optimize the allocation of educational resources, providing robust policy support for curriculum development, teacher training, and technical assistance. By establishing inter-departmental collaboration mechanisms, it can break down resource fragmentation and disciplinary barriers, achieving deep integration in education, science and technology, and industry. Second, improving the mechanisms and systems for interdisciplinary training is essential. On one hand, a policy incentive mechanism should be established, such as setting up special funds and rewarding innovative practices, to encourage schools and teachers to explore and reform STEM teaching. On the other hand, pilot projects and balanced development should be promoted. Pilot projects are a key approach to implementing STEM education. Representative schools should be selected from different regions and educational stages to conduct STEM education pilot projects, accumulating teaching experience and forming replicable models. Through the promotion of these pilots, successful teaching cases and effective methods can be widely applied to other regions and schools, promoting balanced educational development. For remote areas and regions with limited educational resources, policy support should be increased to ensure that students have equal access to high-quality STEM education.

4.2. Improve Digital Literacy and Explore Local Characteristics

In the context of interdisciplinary STEM education, the professional development and skill enhancement of teachers are crucial for the successful implementation of interdisciplinary education. STEM teaching demands that teachers possess multidimensional skills, including integrating multiple disciplines, designing projects, and applying technology. However, traditional teacher training often focuses on single-discipline teaching abilities, leading to a lack of professional competence in interdisciplinary education. Additionally, the absence of curriculum design that integrates local cultural resources has failed to fully engage students 'interest in learning and foster cultural identity. Firstly, specialized training for teachers' interdisciplinary skills is needed, along with the development of standardized interdisciplinary course templates and diverse training formats such as online courses, thematic seminars, and practical workshops. By forming teacher learning communities, we can promote the improvement of practical skills and innovative teaching methods through collaboration. Secondly, there should be enhanced training and support for digital literacy, providing teachers with operational training in intelligent technologies, enabling them to master the use of virtual labs, programming software, and other tools, thus facilitating the deep integration of technology and teaching content in the classroom. Thirdly, local characteristics should be integrated into the curriculum to enrich its content, combining regional natural resources, cultural traditions, and social needs to develop STEM courses with local features. For example, using local ecological environments and historical culture as the backdrop for the curriculum, designing project activities that are closely related to real life can enhance students' interest in learning and strengthen their cultural identity. Lastly, the synergy between teachers and technology should be leveraged, with teachers designing flexible teaching activities based on student needs in STEM education, using intelligent technology as an auxiliary tool to provide support and convenience, and guiding, inspiring, and providing feedback to facilitate deep learning.

4.3. Establish an Evaluation System to Promote Equity in Education

The outcomes of interdisciplinary education are difficult to quantify, and the current evaluation systems fail to fully measure the core competencies of new talents. Developing evaluation indicators and methods for STEM interdisciplinary education driven by intelligent technology is essential. These should not only assess students 'mastery of subject knowledge but also focus on evaluating their comprehensive qualities, such as interdisciplinary thinking, innovation, and practical skills, to provide a comprehensive and objective reflection of their learning achievements. Traditional student assessment systems often rely too heavily on single-subject knowledge and test scores, which fails to fully reflect students' comprehensive abilities and problem-solving skills in STEM interdisciplinary learning. Interdisciplinary learning outcomes emphasize students 'ability to apply multidisciplinary knowledge in complex situations, as well as the development of critical thinking, teamwork, and creativity, which are often overlooked in existing evaluation systems. First, develop multi-dimensional evaluation indicators that consider students' subject integration, innovative thinking, teamwork, and problem-solving skills, forming a multi-dimensional evaluation framework focused on comprehensive qualities. Second, adopt performance-based evaluation methods, using project presentations, research reports, and real-world problem-solving to assess students 'interdisciplinary thinking and practical skills, combining process and outcome evaluations. Third, introduce intelligent technology to optimize personalized evaluations, using AI to dynamically track students' learning performance, generate personalized feedback through learning analysis, help students identify their strengths and weaknesses, and provide targeted improvement suggestions. Fourth, promote fairness and inclusiveness. In the evaluation process, special attention should be paid to the fairness of students from different regions and backgrounds, so as to avoid unfair evaluation results caused by uneven resources. In addition, differentiated evaluation schemes should be designed for special student groups to ensure the inclusiveness and scientificity of the evaluation system.

4.4. Strengthen Privacy Protection and Ensure Data Security

With the widespread application of intelligent technologies in STEM education, big data, artificial intelligence, and virtual reality have significantly enhanced teaching effectiveness and personalized learning. However, the use of these technologies also involves the collection, storage, and processing of a large amount of student privacy data, posing new challenges to data security and privacy protection. Establishing a comprehensive data security protection mechanism is crucial for the healthy development of STEM education. Firstly, strict laws and regulations on data collection, storage, and usage should be established at both national and local levels to provide a legal basis and enforce compliance for the use of educational data. These regulations should clearly define the scope of data collection, usage rights, and storage periods to ensure the legality and compliance of data. Additionally, clear policies should be formulated to address issues such as cross-border transmission of educational data and data sharing on third-party platforms, preventing data misuse or illegal outflow. Secondly, advanced data encryption technology should be adopted. Technical measures are fundamental to ensuring data security. During data storage and transmission, high-strength encryption algorithms, such as end-to-end encryption and differential privacy protection, should be used to prevent sensitive information from being intercepted or accessed illegally. Educational data platforms should establish strict access permission management mechanisms, using two-factor authentication and dynamic monitoring systems to ensure that only authorized users can access relevant data. Furthermore, regular vulnerability scans and security assessments should be conducted to promptly address potential security risks. Thirdly, a dedicated regulatory body should conduct real-time monitoring of the collection and use of educational data. The institution should operate independently of educational technology providers and school management to ensure the fairness and authority of oversight. The regulatory body's responsibilities include reviewing the legality of data collection and usage, monitoring risks of data breaches or misuse, handling data security incidents, and regularly publishing reports on educational data security. A data audit mechanism should be established to trace the use of educational data and hold parties accountable, thereby enhancing the transparency and security of data management. Finally, it is essential to enhance the data security awareness among teachers and students. This can be achieved through specialized training sessions, promotional activities, and practical exercises, which will help teachers and students understand the importance of data privacy protection and its practical impact in STEM education

Author Contributions

The core contributions of this study were completed collaboratively by the two authors based on their respective research expertise. W.X.: Focused on the construction of the research framework and theoretical analysis, systematically reviewing the theoretical context of integrating STEM education with intelligent technologies in the era of digital intelligence to promote the growth of new quality talents, clarifying its development landscape and implementation paths; identifying existing deficiencies and challenges, and providing targeted recommendations. T.W.: Focused on designing practical pathways and integrating interdisciplinary perspectives, combining educational technology and intelligent technology theories to provide detailed guidance for drafting the policy recommendation section. Overall, through division of labor and collaboration, the two authors have not only enriched the theoretical achievements of educational digitalization but also provided a research model with academic and theoretical significance for the digital transformation of education. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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