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TECHNOLOGY AND SCIENCE-BASED EDUCATION AS A PILLAR OF INTELLECTUAL DEVELOPMENT IN THE 21ST CENTURY: A LITERATURE REVIEW ON THE DEVELOPMENT OF ADAPTIVE, INCLUSIVE, AND SUSTAINABLE LEARNING MODELS IN THE DIGITAL AGE

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Abstract

This study aims to examine the role of technology and science-based education as a pillar of intellectual development in the 21st century through a literature review approach. Digital transformation has changed the paradigm of education from a conventional model to an adaptive, inclusive, and sustainable learning system. Technology not only functions as a learning tool, but also as a catalyst for the formation of a creative, critical, and innovative *knowledge-based society*. This study highlights how the integration of technology and science strengthens intellectual competitiveness through expanded access, personalised learning, and the strengthening of 21st-century competencies such as critical thinking, collaboration, communication, and digital literacy. In addition, a conceptual framework for adaptive, inclusive, and sustainable learning models has been developed as a strategic solution to global challenges in modern education. The results of the study show that the successful implementation of this model depends on the readiness of human resources, digital infrastructure support, and progressive and humanistic education policies. Thus, technology- and science-based education not only improves academic quality but also shapes intellectual and social characters that are relevant to the demands of the digital age without abandoning human values.

Keywords: technology-based education, science, intellectual development, adaptive learning, inclusive, sustainable, digital era

Introduction

In the last two decades, developments in technology and science have become a major force revolutionising all aspects of human life, including education. The digital transformation triggered by advances in information technology, artificial intelligence (AI), and global communication networks has changed the paradigm of how humans learn, think, and interact (Aslan et al., 2020) ; (Aslan & Imelda, 2025) . Education, which was once conventional with a face-to-face pattern, has now shifted to a more flexible, adaptive, and personalised technology-based learning model. This shift requires educational institutions to not only be providers of information but also centres of intellectual innovation capable of directing their human resources to be relevant to the dynamics of the 21st century. This phenomenon also confirms that technology and science-based education is not just a

trend, but a fundamental need in the intellectual development of modern society (Rahman & Aslan, 2025) ; (Nisa et al., 2021) .

Intellectual development in the context of the 21st century no longer focuses solely on factual knowledge, but also on critical, creative, collaborative, and communicative thinking skills. These competencies are known as *21st Century Skills*, which can only be developed through an education system that is able to adapt to global changes and utilise technology strategically (Jiang & Wei, 2025) . In this case, science and technology (IPTEK) become the driving force that enables education to shape individuals who are not only academically intelligent, but also digitally literate, resilient to uncertainty, and capable of innovation (Tlili & Shehata, 2023) . However, challenges arise when the digital divide, low technological literacy, and unequal access to education become major obstacles to equitable learning quality across regions, particularly in developing countries.

Indonesia, like many other countries, is in the midst of an educational transformation towards an inclusive and sustainable digital ecosystem. Through various policies such as *Merdeka Belajar* (Freedom of Learning), curriculum digitalisation, and the development of online learning platforms, the government is striving to bridge the gap between traditional and modern education (Florian & Black-Hawkins, 2022) . However, the success of this transformation is highly dependent on the ability of the education system to develop adaptive learning models — that is, models capable of adjusting methods, media, and pedagogical approaches based on the needs and characteristics of learners (Ariani & Wenda, 2025) . This highlights the importance of conducting in-depth studies on the integration of technology and science in effective learning design to enhance intellectual competitiveness in the global era.

Conceptually, technology-based education opens up opportunities for more personalised, contextual, and interactive learning. Technology enables educators to apply the principle *of differentiated learning*, where each learner can learn according to their own style and pace. For example, data-driven and artificial intelligence-based learning systems can map students' weaknesses and strengths in real time, then recommend the most appropriate learning materials and strategies (Crompton & Burke, 2023) . This approach not only increases learning effectiveness but also creates a more human and meaningful learning experience. However, the implementation of this model must be balanced with an ethical understanding of data privacy, inclusivity, and efforts to prevent digital exclusion of groups that do not yet have adequate access to technology (Hamid & Aslan, 2025) ; (Trinova et al., 2025) .

In addition to adaptability, the dimension of inclusivity is an important element in 21st-century education. Inclusive education is not merely about providing equal access to all individuals, but also ensuring that every learner, regardless of their physical, social, economic, or geographical conditions, has equal opportunities to develop. In the digital context, inclusivity encompasses empowering communities through the provision of accessible technology, learning content that is friendly to all, and the design of learning environments that support diverse learning styles. Thus, the application of technology in

education must be directed towards removing social and geographical barriers, not widening the gap (Li & Wang, 2024) .

ity in technology and science-based education is also a strategic issue that cannot be ignored. education is not only related to environmental policies, but also to the ability of the education system to adapt to change without losing its direction and human values (Hidayah & Yuliawati, 2024) . Sustainable learning models must take into account the needs of the future labour market, the ethics of technology use, and the development of a culture of *lifelong learning*. This means that the education system does not stop at academic achievement alone, but continues to nurture individuals who are able to learn, adapt, and create amid complex changes (Berman et al., 2021) .

The transformation of education in the digital age also requires a redefinition of the role of educators. Teachers and lecturers are no longer merely conveyors of information, but function as facilitators, mentors, and curators of knowledge in the midst of a vast sea of information. With the support of technology, educators can guide learners to think reflectively, evaluate information sources, and actively participate in the process of knowledge creation (Viberg & Khalil, 2024) . However, a major challenge lies in the digital competence readiness of the educators themselves. Therefore, developing the digital capacity of teaching staff is an integral part of the strategy for implementing technology-based education.

From the learners' perspective, digital learning requires independence, discipline, and adequate digital literacy. Access to devices and networks does not guarantee success if it is not balanced with the ability to think critically in utilising technology for learning. Therefore, strengthening character and digital ethics is the main foundation in preparing a generation that is not only intellectually intelligent but also socially responsible in the use of technology. Education that prioritises a balance between technological dimensions and humanistic values will produce a society that is both intellectually capable and ethical (Green Pustaka Indonesia, 2024) .

The development of adaptive, inclusive, and sustainable learning models is a strategic response to the above challenges. This model emphasises the importance of pedagogical flexibility, local contextual relevance, and a long-term orientation towards human development. Through an adaptive approach, education is no longer one-way, but dynamic and responsive to learning feedback. Through inclusiveness, the learning process becomes a means of equal opportunity and social justice. Meanwhile, through the principle of sustainability, education is able to continue to evolve without losing its human values and intellectual progress (Maftuh, 2024) .

Thus, technology and science-based education is crucial to understanding the direction of development and its implications for the intellectual development of the nation. Furthermore, we must be aware that the future of education is determined by the extent to which we are able to integrate technology and science in an ethical, humanistic, and sustainable manner. Education does not only aim to produce a productive workforce, but also to develop creative, critical thinkers with high intellectual drive. Therefore, a

collaborative commitment between the government, educational institutions, society, and industry is needed to create an inclusive and empowering digital learning ecosystem . Within that framework, this study presents a comprehensive review of the role of technology and science-based education as the foundation for intellectual development in the 21st century, which is realised through adaptive, inclusive, and sustainable learning models.

Research Method

The research method used in this study is a literature review, which is a research approach that focuses on searching, analysing, and synthesising various relevant scientific literature sources to gain an in-depth understanding of the topic being studied. This study did not involve field data collection but used secondary sources such as scientific journals, academic books, conference proceedings, research reports, and education policy documents published in the last one to two decades (Eliyah & Aslan, 2025) . The review process was carried out through the stages of problem identification, literature selection based on relevance and credibility, content analysis of previous theories, concepts, and research findings, and the preparation of a conceptual synthesis to form a complete framework of thinking. This method was chosen because it is in line with the conceptual and exploratory objectives of the study, namely to develop a theoretical understanding of technology-based education and science as pillars of 21st-century intellectual development and to formulate adaptive, inclusive, and sustainable learning models in the digital age (Levy & Ellis, 2006) .

Results and Discussion

Technology-Based Education and Science as Pillars of Intellectual Development

Education has long been a key instrument in building human civilisation, but in the 21st century, this role has undergone a significant redefinition due to rapid advances in technology and science. Whereas in the past education was seen as a process of transferring knowledge from teachers to students, today education must be viewed as a dynamic system that enables learners to construct knowledge independently through interaction with technology and global information sources (Ridwan et al., 2025) ; (Aslan & Azizan, 2025) . In this context, technology-based education and science become fundamental pillars in the formation of intellectual intelligence that does not only rely on memorisation, but also on critical thinking, problem-solving, and *lifelong learning*.

The integration of technology in education paves the way for efficiency, flexibility, and expanded access to learning that was previously difficult to achieve with conventional systems. Digital platforms, online learning, artificial intelligence, and data-driven learning systems enable students to have a more interactive and personalised learning experience that suits their abilities and interests (Maftuh, 2024) . Technology acts as a catalyst in strengthening the process of internalising knowledge, connecting theory and practice, and creating learning spaces without geographical and time constraints. The existence of

technology creates new conditions where knowledge is no longer static and centralised, but rather becomes a fluid, collaborative, and continuously evolving ecosystem (Viberg & Khalil, 2024) .

Science, on the other hand, provides the epistemological basis that ensures the use of technology in education remains rational and evidence-based. Without a scientific foundation, the use of technology risks becoming merely a pragmatic trend that does not support improvements in learning quality. Therefore, the synergistic relationship between technology and science creates a balance between innovation and substance. Science provides a methodological foundation for the development of digital curricula, instructional design, and learning evaluation, while technology provides concrete instruments that make the learning process more efficient and relevant to the needs of the modern era (Berman et al., 2021) .

In the context of intellectual development, technology- and science-based education serves to shape individuals with high reasoning abilities, logical thinking, and the capacity to adapt to the complexities of the modern world. Educated individuals in the digital age are required not only to understand concepts, but also to be able to process information, make decisions based on data, and innovate using technology (Viberg & Khalil, 2024) . Thus, intellectual development is not merely an improvement in cognitive abilities, but also a strengthening of digital and scientific literacy that enables society to become producers of knowledge, not just consumers of information.

Technology-based education also encourages a transformation in the learning culture within society. Through technology, the learning process is no longer confined to the classroom but can take place anywhere and anytime. This concept is known as *ubiquitous learning*, where learners utilise various digital media to learn autonomously and collaboratively. Technology-based learning supports the characteristics of *self-directed learners*, namely individuals who have high initiative, responsibility, and independence in managing their learning process. This transformation reflects a shift from the *teacher-centred learning* paradigm to *learner-centred learning*, where learners become the main actors in their own intellectual development (Mudzakir & Aslan, 2025) ; (Sampe & Aslan, 2025) .

At the same time, the application of technology in education also strengthens students' analytical and creative abilities. Scientific simulation applications, virtual laboratories, or the use of interactive software help students understand complex concepts that are difficult to explain theoretically. In science learning, for example, digital experiments allow students to visualise chemical or physical processes that previously could only be explained through text. The ability to understand, predict, and manipulate scientific data trains their logical and imaginative reasoning to create innovative solutions . Thus, science and technology are not only learning aids, but mechanisms that shape scientific and productive thinking (Sitorus, 2025) .

From a social perspective, technology and science-based education accelerates the formation of *a* knowledge-based *society*. Such a society is characterised by collaborative

abilities in creating, sharing, and applying knowledge to improve quality of life. Communication technologies, such as the internet and academic social media, accelerate the exchange of ideas across cultures and disciplines, thereby enriching students' global perspectives (Brooks-Young, 2010) . Intellectual development in this context is no longer local in nature, but global in scale — students become part of an international network of learners, researchers, and innovators oriented towards the advancement of human civilisation (Wageningen et al., 2011) .

However, the urgency of implementing technology-based education cannot be separated from the serious challenge of the *digital divide*. Not all individuals or educational institutions have equal access to adequate digital devices and infrastructure. This has the potential to create new inequalities in the intellectual capabilities of society. Therefore, comprehensive policies are needed to ensure that the integration of technology in education is carried out equitably and fairly. The government, educational institutions, and the private sector must collaborate to provide digital infrastructure, technology skills training for teachers, and a curriculum that is contextual to local realities (Asad et al., 2024).

Beyond access, ethical dimensions and human values are crucial issues in the use of educational technology. Technology-based education must not distance humans from their essence. The use of technology must remain oriented towards character development, empathy, and social responsibility. Therefore, intellectual development must be holistic, balancing cognitive and moral intelligence. A society that is technologically savvy but lacks social sensitivity has the potential to cause an ethical crisis in the future. Therefore, science and technology-based education must always integrate the principles of digital ethics, moral literacy, and awareness of the social impact of technological innovation (Dede & Mishra, 2023) .

Technology and science-based education also requires educational institutions to change their roles to be more adaptive to the changing times. Schools and universities are required to become centres of innovation development, not just places for delivering lesson material. Educational institutions need to build a culture of research, scientific exploration, and the use of technology to solve real problems in society (Selwyn & Hillman, 2024) . Thus, education becomes a strategic means of producing a generation of innovators who can contribute directly to national and global development. The active involvement of students in technology-based scientific research strengthens the process of sustainable intellectual development (Southgate & Smith, 2025) .

The role of educators in this scheme has also changed fundamentally. Teachers and lecturers are no longer the sole source of knowledge, but function as facilitators, mentors, and *learning designers* who guide learners in managing information and building new knowledge- . To support this role, educators need to have digital literacy, technological pedagogical skills, and a commitment to research-based learning. Mastery of technology must be accompanied by sensitivity to the needs of learners so that the learning process

remains contextual and oriented towards the development of individual potential (Romadhon & Aslan, 2025) ; (Aslan & Hajiri, 2025) .

On the other hand, strengthening collaboration between the education sector, industry, and research institutions is an important element in optimising the role of science and technology for intellectual development. The *triple helix* collaboration model — between academics, government, and industry — creates a learning ecosystem that is relevant to market needs and global technological developments. Through this cooperation, students gain practical experience in applying the theories they have learned to the real world, while industry gains competent and innovative human resources. This kind of collaboration strengthens the connection between education and socio-economic development (Southgate & Smith, 2025) .

In the long term, technology- and science-based education forms the foundation for the realisation of *a learning society*. This society is characterised by openness to new knowledge, adaptability to change, and a spirit of lifelong learning. Intellectuality in the context of a learning society is no longer the monopoly of academics, but a universal competence possessed by every individual. Thus, education does not stop at formal institutions, but permeates everyday life through interaction with technology and science (Redecker, 2023) .

Thus, technology and science-based education has a strategic role as a main pillar of intellectual development in the 21st century. The integration of the two not only enriches learning methods but also changes the very nature of education itself into a process of shaping adaptive, innovative, and characterful individuals. The resulting intellectual development is multidimensional — combining logical and imaginative thinking with human values that form the basis of a sustainable civilisation. With proper integration, science and technology are not only educational tools but also the foundation of a new civilisation that leads humanity towards a knowledgeable and ethical global society.

Adaptive, Inclusive, and Sustainable Learning Models in the Digital Age

The development of digital technology has brought significant changes to the educational paradigm, especially in terms of how the learning process is designed, implemented, and evaluated. Amidst the acceleration of information and the complexity of global challenges, the education system is required to be more responsive, flexible, and contextual to the needs of students. One approach that has emerged as a response to these challenges is the adaptive, inclusive, and sustainable learning model (Trilling & Fadel, 2009) . This model not only emphasises the application of technology as a tool, but also places it at the core of a pedagogical strategy that is capable of adapting the learning experience to diverse individual characteristics and social realities (Sitopu et al., 2024) .

The adaptive learning model is an approach that allows the learning process to adapt to learners' cognitive needs, learning styles, and pace. In this model, technology serves as the primary instrument that continuously collects learning data to generate

personalised learning recommendations (Maulida, 2024) . For example, an artificial intelligence-based *Learning Management System (LMS)* can analyse student activity patterns, identify difficulties encountered, and automatically adjust content or material difficulty levels. This approach is based on the principle *of data-driven education*, where pedagogical decisions are made based on empirical data analysis of student behaviour and learning achievements, rather than generalised assumptions (Ariani, 2023) .

The main advantage of adaptive learning is its ability to accommodate the diversity of abilities and potential of each learner. Conventional education systems often set a uniform curriculum that does not take into account differences in learning speed, interests, or socio-cultural backgrounds of students. As a result, some learners fall behind, while others lack adequate challenges (Graf & Kinshuk, 2021) . Through adaptive learning, the learning process becomes more humanised and relevant as it allows for personalisation of materials and real-time feedback. Adaptivity not only improves academic outcomes but also strengthens students' intrinsic motivation through meaningful and contextually relevant learning experiences.

Meanwhile, the inclusive learning model ensures that every individual has equal access and opportunity to obtain education, without being limited by physical, economic, geographical, or cognitive differences. In the digital context, inclusivity means providing technology and learning resources that are accessible to all segments of society, including marginalised groups (Redecker, 2023) . This principle is reflected in the application of *Universal Design for Learning (UDL)*, a learning design approach that considers learner diversity from the planning stage. For example, learning content available in various formats—text, audio, video, interactive—enables students with certain limitations to continue learning optimally. Thus, technology acts as a bridge to social justice in education, rather than a source of new inequality (Southgate & Smith, 2025) .

The integration of technology in inclusive learning also encourages cross-border collaboration that enriches students' insights. Digital platforms enable interaction between students from different geographical and cultural backgrounds, broadening their global perspective on human diversity. Furthermore, this approach instils the values of tolerance and social empathy as part of intellectual character building. Technology-supported inclusive education not only teaches academic skills but also strengthens solidarity and collective awareness of social issues at the local and global levels (Guna et al., 2024) .

The third component in this model is sustainability, which emphasises the importance of the continuity of the educational process in the long term, in terms of resources, relevance, and its impact on the environment and society. Sustainable learning does not stop at the transfer of short-term knowledge, but fosters *a culture of lifelong learning*. In this case, technology becomes a medium that facilitates continuous connectivity between individuals, information, and learning communities. For example, the concept of *open educational resources (OER)* opens up opportunities for the wider

community to learn independently with open and free resources, supporting equal learning opportunities and sustainable digital literacy (Selwyn & Hillman, 2024) .

Furthermore, sustainability in learning is also related to the ability of the education system to adapt to social dynamics and new technological developments. Learning models must be designed to be flexible in order to remain relevant in the face of changes such as the emergence of generative artificial intelligence, the Internet of Things (*IoT*), and virtual reality technology (Dede & Mishra, 2023) . Therefore, education needs to transform from a static system into a dynamic and resilient learning ecosystem. Educators and learners need to be equipped with competent digital skills and reflective abilities to continuously update their ways of thinking and learning amid these changes.

The synergy between the principles of adaptability, inclusiveness, and sustainability can give rise to a learning model that is not only academically effective but also relevant to human values and *sustainable development* goals. Adaptive education ensures that each individual can develop according to their potential; inclusive education guarantees equitable access; and sustainable education affirms a commitment to the future of the next generation. These three principles form the foundation for a resilient and visionary education system in the digital age (Asad et al., 2024) .

In its implementation, the success of adaptive, inclusive, and sustainable learning models depends heavily on the ability of educational institutions to integrate policies, infrastructure, and human resources (Wageningen et al., 2011) . Continuous training is needed for teachers to understand the use of learning technology and educational data analysis, as well as a flexible curriculum to support personalised learning. The government also needs to create regulations and budgetary support that enable all educational institutions — including those in disadvantaged areas — to adopt digital models evenly. A cross-sectoral approach between education, technology, and public policy is key to maintaining the continuity of this innovation (Brooks-Young, 2010) .

Thus, adaptive, inclusive, and sustainable learning models in the digital age are not merely conceptual frameworks, but concrete strategies for creating a smart, creative, and ethical learning society. This model encourages education to function as an open ecosystem that constantly evolves based on the needs of the times, combining the power of technology with human values. Ultimately, the success of implementing this model will determine the extent to which education can fulfil its function as the main driver of intellectual and social development in the 21st century, leading humanity towards an advanced and just civilisation.

Conclusion

Technology and science-based education is the main foundation for building human intellectual capacity in the 21st century. The integration of science and technology and education not only changes the way humans acquire and produce knowledge, but also shifts the essence of education towards a more open, dynamic, and competency-based system. Through the use of digital technology, the learning process becomes more

efficient, interactive, and personalised, enabling students to develop their potential optimally. Science provides direction and methodology so that technological innovation in education does not lose its theoretical basis, while technology bridges practical applications that expand access and learning effectiveness. Both play a synergistic role in shaping a knowledge society that is adaptive to global changes and highly competitive in the era of the 4.0 and 5.0 industrial revolutions.

In the context of developing learning models, adaptability, inclusivity, and sustainability are important pillars that ensure education is relevant to the needs of learners and future challenges. Adaptive learning allows for differentiation of approaches according to individual learning styles and abilities, while inclusive learning ensures equitable access for all segments of society, including vulnerable groups. Sustainability then ensures that the educational process does not stop at academic achievement alone, but continues to foster a culture of lifelong learning. These three elements support each other and create a learning ecosystem that is human-centred, ethical, and capable of navigating the complexities of an ever-changing digital world.

Overall, technology and science-based education is not only an instrument for improving the quality of human resources, but also a civilisational strategy for creating an ethical and equitable intellectual society. Strengthening the integration of science and technology in the education system must be accompanied by policies that favour equal access, the development of digital literacy, the improvement of educators' capacities, and support for sustainable infrastructure. In this way, education will truly function as a pillar of intellectual development for the nation — producing individuals who are not only intelligent in their thinking, but also wise in their actions and responsible for the advancement of humanity in the digital age.

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