

Review Article

The Importance of Artificial Intelligence (AI) Tools in the Modern Science, Engineering and Technological Research and Innovations: A Review

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Abstract

Artificial Intelligence (AI) tools are rapidly transforming the landscape of modern science, engineering, and technological research and innovation. Their ability to process vast datasets, identify complex patterns, and generate predictive models far surpasses human capabilities, leading to accelerated discovery and unprecedented advancements across diverse fields. In scientific research, AI algorithms are instrumental in analyzing genomic data, predicting protein structures, and simulating complex environmental systems, significantly shortening the time required for breakthroughs in areas like medicine, climate science, and materials science. In engineering, AI is revolutionizing design optimization, predictive maintenance, and autonomous systems. Engineers are leveraging AI-powered design tools to create more efficient and sustainable structures, while predictive maintenance algorithms are reducing downtime and improving the reliability of critical infrastructure. The development of self-driving cars, autonomous robots, and smart manufacturing processes is heavily reliant on the sophisticated AI algorithms that enable these systems to perceive, learn, and adapt to their environments. Furthermore, AI is driving innovation in technological research by enabling the development of novel algorithms, hardware architectures, and computing paradigms. AI is being used to design more energy-efficient processors, create advanced materials with tailored properties, and develop new methods for data storage and retrieval. The ability of AI to automate repetitive tasks, generate hypotheses, and identify unexpected correlations is freeing up researchers to focus on more creative and strategic aspects of their work. By augmenting

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human intelligence and accelerating the pace of experimentation, AI tools are proving indispensable for pushing the boundaries of scientific knowledge, engineering prowess, and technological advancements, ultimately shaping a future driven by intelligent systems and data-driven insights.

Keywords

Artificial Intelligence, Research and Innovation, Science and Technology, Engineering, Empowering

1. Introduction

Artificial Intelligence (AI) is no longer a futuristic fantasy; it's a rapidly evolving field permeating virtually every facet of modern life. Defining AI, however, proves to be a surprisingly complex task, as the very notion of "intelligence" remains a subject of philosophical debate. Generally, AI encompasses the development of computational systems capable of performing tasks that typically require human intelligence, such as learning, problem-solving, decision-making, and perception. These systems leverage algorithms, data, and computational power to mimic, augment, or even surpass human cognitive abilities. The ambiguity in defining AI stems from its interdisciplinary nature, drawing from computer science, mathematics, philosophy, psychology, and neuroscience, each contributing its own perspective and influencing the scope of what constitutes "intelligent" behavior [1-10].

One of the earliest and most influential definitions of AI comes from Marvin Minsky, a pioneer in the field, who described it as "the science of making machines do things that would require intelligence if done by men"[11-17]. This definition, while broad, highlights the core objective of AI - to automate tasks that necessitate higher-level cognitive functions. It subtly acknowledges the anthropocentric view that often underlies our understanding of intelligence, measuring machine performance against human capabilities. This perspective is further echoed in the Turing Test, proposed by Alan Turing in 1950, which suggests that a machine can be considered "intelligent" if it can convincingly imitate human conversation to the point where a human evaluator cannot distinguish it from a real human [36-39]. While the Turing Test remains a cornerstone in the history of AI, it has also faced criticism for its reliance on mimicry rather than genuine understanding.

A more nuanced definition is offered by Nils Nilsson, another influential figure in AI, who describes it as "that activity devoted to making machines intelligent, and intelligence is that quality that enables an entity to function appropriately and with foresight in its environment" [15-18]. This definition shifts the focus from simply replicating human behavior to emphasizing the ability of an AI system to adapt and perform effectively in a given environment. It highlights the importance of rationality and goal-directed behavior, suggesting that an intelligent system should be able to perceive its sur-

roundings, reason about them, and take actions that lead to desired outcomes. This perspective aligns with the concept of "rational agents," as defined by Russell and Norvig (2020), who propose that AI systems should be designed to act rationally, aiming to achieve the best possible outcome or, when uncertain, the best expected outcome.

The field of AI is often categorized into different approaches, each with its own underlying principles and methodologies. One common distinction is between "strong AI" and "weak AI." Strong AI, also known as Artificial General Intelligence (AGI), aims to create machines that possess human-level intelligence, capable of performing any intellectual task that human beings can [10]. Such systems would theoretically possess consciousness, self-awareness, and the ability to learn and adapt in a truly general manner. While strong AI remains a long-term aspiration, no existing AI system currently meets this definition. Conversely, weak AI, also known as narrow AI, focuses on developing systems that excel at specific tasks, such as image recognition, natural language processing, or game playing. These systems are designed to perform a limited set of functions with high proficiency, but they lack the general intelligence and adaptability of a human being. The vast majority of AI applications today fall under the category of weak AI.

Another important distinction within AI is between symbolic AI and connectionist AI. Symbolic AI, also known as rule-based AI, relies on explicit rules and logical reasoning to solve problems [24]. These systems are typically programmed with a set of predefined rules that govern their behavior. While symbolic AI can be effective for tasks that require precise reasoning and knowledge representation, it often struggles to handle complex, unstructured data or situations that require learning from experience. Connectionist AI, on the other hand, is based on artificial neural networks, which are inspired by the structure and function of the human brain [33]. These networks consist of interconnected nodes that process information in parallel, allowing them to learn patterns and relationships from large datasets through a process called "deep learning." Deep learning has revolutionized many areas of AI, particularly in image recognition, natural language processing, and speech recognition, and has become a dominant approach in many applications.

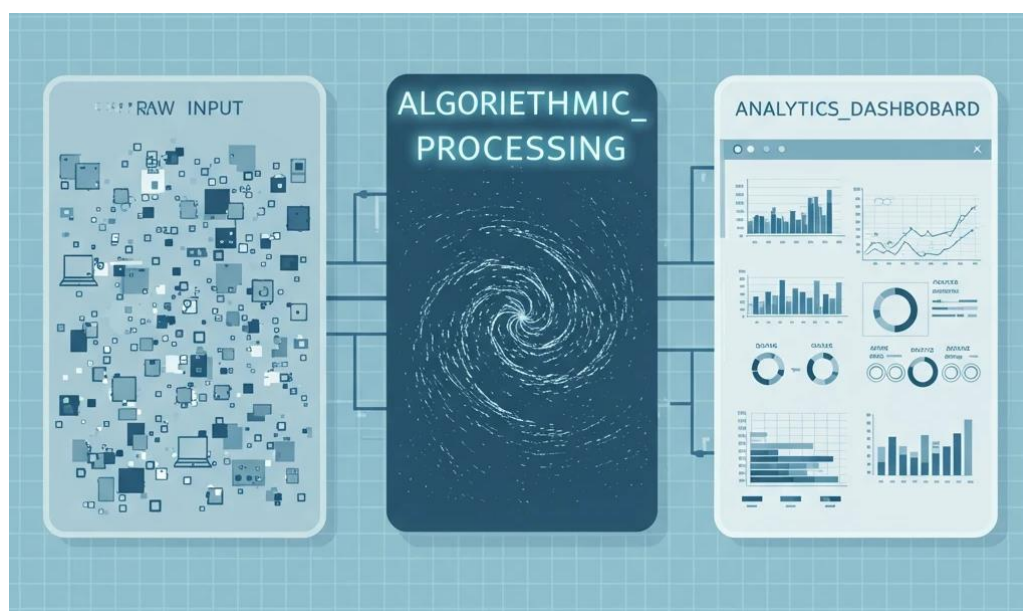


Figure 1. A systematic diagram of the working of AI technology.

The increasing prevalence of AI in various sectors necessitates a comprehensive understanding of its capabilities, limitations, and ethical implications. As AI systems become more sophisticated, they raise important questions about bias, fairness, accountability, and transparency. It is crucial to ensure that AI is developed and deployed responsibly, considering its potential impact on society and individual well-being. Furthermore, education and public awareness are essential to foster a broader understanding of AI and its potential benefits and risks. As AI continues to evolve, the ongoing dialogue between researchers, policymakers, and the public will be critical to shaping its future and ensuring that it serves humanity in a positive and equitable manner. In conclusion, AI encompasses a diverse range of technologies and approaches aimed at creating intelligent systems. While defining AI remains a challenge, the underlying goal is to develop systems that can perform tasks requiring human intelligence, ultimately leading to automation, increased efficiency, and innovative solutions across various domains.

2. The Importance of Artificial Intelligence (AI) Tools in Science, Engineering and Technology

Artificial intelligence (AI) has emerged as a transformative force across diverse domains, revolutionizing scientific inquiry, engineering practices, medical advancements, and technological innovations. Its significance stems from its capacity to analyze vast datasets, identify intricate patterns, and generate data-driven insights that surpass human capabilities. In science, AI algorithms accelerate research by predicting protein structures, simulating complex systems, and optimizing experimental designs, enabling scientists to tackle

previously intractable problems and push the boundaries of knowledge. In engineering, AI empowers engineers to design more efficient and sustainable infrastructure, optimize manufacturing processes, and develop intelligent systems that adapt to changing conditions, leading to improved performance and resource utilization. The medical field witnesses a paradigm shift with AI-powered diagnostic tools, personalized treatment plans, and drug discovery platforms, enhancing diagnostic accuracy, tailoring therapies to individual patient needs, and accelerating the development of life-saving medications. In technology, AI fuels the development of autonomous vehicles, intelligent robots, and personalized digital assistants, transforming industries and enhancing human experiences. As AI continues to evolve, its potential to address global challenges, drive innovation, and improve the human condition is immense, making it an indispensable tool for professionals across diverse fields.

AI's impact on science is particularly profound, accelerating scientific discovery and fostering new insights into complex phenomena. For instance, in genomics, AI algorithms analyze vast genomic datasets to identify disease-causing genes, predict drug responses, and develop personalized therapies, revolutionizing the treatment of genetic disorders and cancers [30]. Furthermore, AI plays a crucial role in materials science, where it predicts the properties of novel materials, optimizes material synthesis processes, and accelerates the discovery of materials with desired characteristics for various applications [6]. By automating complex tasks, uncovering hidden patterns, and generating novel hypotheses, AI empowers scientists to conduct more efficient and impactful research, leading to breakthroughs in various scientific disciplines. The ability of AI to analyze complex systems and generate data-driven predictions is revolutionizing the way scientific research is conducted, accelerating the pace of

discovery and opening up new avenues for exploration.

In engineering, AI is revolutionizing design, manufacturing, and operations, leading to more efficient, sustainable, and resilient systems. AI-powered design tools enable engineers to explore a wider range of design options, optimize designs for performance and cost, and identify potential design flaws early in the development process [41]. In manufacturing, AI algorithms optimize production schedules, predict equipment failures, and control robotic systems, leading to increased productivity, reduced waste, and improved product quality [40]. Furthermore, AI plays a crucial role in infrastructure management, where it monitors the condition of bridges, buildings, and other infrastructure assets, predicts maintenance needs, and optimizes traffic flow, ensuring the safety and efficiency of transportation networks [10]. By automating complex tasks, improving decision-making, and optimizing system performance, AI empowers engineers to design, build, and operate more efficient and sustainable infrastructure, contributing to a more resilient and prosperous society. The integration of AI into engineering practices is transforming the way engineers approach design, manufacturing, and operations, enabling them to create innovative solutions to complex challenges.

The medical field is undergoing a profound transformation with the integration of AI, leading to improved diagnostics, personalized treatments, and drug discovery. AI-powered diagnostic tools analyze medical images, such as X-rays, CT scans, and MRIs, to detect diseases with greater accuracy and speed, enabling earlier and more effective treatment [8]. AI algorithms analyze patient data to predict disease risks, personalize treatment plans, and monitor patient outcomes, leading to improved patient care and reduced healthcare costs [26]. Furthermore, AI plays a crucial role in drug discovery, where it analyzes vast datasets of chemical compounds, predicts drug efficacy, and identifies potential drug targets, accelerating the development of new medications [27]. By automating complex tasks, improving decision-making and personalizing treatment approaches, AI empowers healthcare professionals to deliver more effective and efficient care, leading to better patient outcomes and a healthier population. The application of AI in medicine is revolutionizing the way healthcare is delivered, enabling personalized and data-driven approaches to diagnosis, treatment, and prevention.

In technology, AI is driving innovation across various sectors, from autonomous vehicles to personalized digital assistants. AI algorithms enable autonomous vehicles to perceive their surroundings, navigate complex environments, and make decisions in real-time, transforming transportation and logistics [3]. AI-powered robots perform tasks in manufacturing, healthcare, and other industries, increasing efficiency, reducing costs, and improving safety. Furthermore, AI powers personalized digital assistants that understand natural language, respond to user requests, and provide personalized recommendations, enhancing user experiences and productivity [13]. By automating complex tasks, enhancing human

capabilities, and creating new products and services, AI is transforming industries and improving the way we live and work. The continuous advancements in AI technology are driving innovation across various sectors, leading to the development of intelligent systems that are more efficient, personalized, and user-friendly.

Artificial intelligence is an indispensable technology that is transforming science, engineering, medicine, and technology. Its ability to analyze vast datasets, identify intricate patterns, and generate data-driven insights has revolutionized scientific research, engineering practices, medical treatments, and technological innovations. As AI continues to evolve, its potential to address global challenges, drive innovation, and improve the human condition is immense. Embracing AI and fostering its responsible development is crucial for professionals across diverse fields to leverage its transformative power and shape a better future. The integration of AI into various sectors is not merely a technological advancement but a paradigm shift that is reshaping the way we live, work, and interacts with the world around us.

3. The Role of Artificial Intelligence (AI) Tools in Environmental Science and Engineering

Artificial Intelligence (AI) tools are revolutionizing Environmental Science and Engineering, offering unprecedented capabilities for monitoring, modeling, and managing our planet's complex ecosystems. From predicting climate change impacts to optimizing resource management and pollution control, AI algorithms are proving invaluable in addressing some of the most pressing environmental challenges. Machine learning models can analyze vast datasets from satellites, sensors, and simulations to identify trends, patterns, and anomalies that would be impossible for humans to detect manually. Furthermore, AI-powered predictive models enable environmental scientists and engineers to anticipate future conditions, such as flood risks, air quality changes, and biodiversity shifts, allowing for proactive mitigation strategies. The integration of AI is not merely an incremental improvement, but a paradigm shift that promises to transform the field, paving the way for more sustainable and resilient environmental practices. This paradigm shift necessitates a comprehensive understanding of AI's capabilities and limitations, guiding its responsible and ethical application in environmental stewardship.

AI plays a crucial role in environmental monitoring by automating the analysis of large datasets collected from various sources. Satellite imagery, for instance, can be processed using computer vision techniques to track deforestation, monitor urban sprawl, and assess the health of vegetation cover. AI algorithms can also analyze data from sensor networks deployed in rivers, lakes, and oceans to monitor water quality parameters, detect pollution events, and predict algal

blooms. In air quality monitoring, AI models can integrate data from ground-based sensors, weather stations, and traffic patterns to create real-time air quality maps and forecast pollution levels. The automation of these processes frees up human experts to focus on more complex tasks, such as developing targeted interventions and policies. Moreover, AI's ability to detect subtle changes and anomalies in environmental data can provide early warnings of potential ecological disasters, enabling timely response and minimizing environmental damage. The increased efficiency and accuracy afforded by AI tools significantly enhance our ability to understand and manage environmental resources.

AI's sophisticated modeling capabilities offer unparalleled insights into complex environmental processes. Climate models, for example, can be enhanced with machine learning algorithms to improve their accuracy and resolution, allowing for more precise predictions of temperature changes, sea-level rise, and extreme weather events. In hydrology, AI models can simulate water flow in rivers and aquifers, predict flood risks, and optimize water resource allocation. Similarly, in ecological modeling, AI can be used to predict species distributions, assess habitat suitability, and forecast the impacts of climate change on biodiversity. These models can also be used to evaluate the effectiveness of different environmental management strategies, providing decision-makers with evidence-based information to guide their actions. The use of AI in environmental modeling not only improves the accuracy of predictions but also accelerates the speed at which simulations can be run, enabling rapid assessment of different scenarios and facilitating adaptive management approaches. This predictive power is essential for developing effective strategies to mitigate and adapt to environmental change.

AI applications extend beyond monitoring and modeling to encompass critical areas of resource management. In agriculture, AI-powered precision farming techniques optimize the use of water, fertilizers, and pesticides, reducing environmental impacts and increasing crop yields. AI algorithms can analyze data from drones, sensors, and weather forecasts to provide farmers with real-time recommendations on irrigation, fertilization, and pest control. In the energy sector, AI can optimize energy consumption in buildings and industrial processes, reduce greenhouse gas emissions, and improve the efficiency of renewable energy systems. Smart grids, powered by AI, can balance electricity supply and demand, integrate renewable energy sources, and prevent blackouts. Furthermore, AI can be used to optimize waste management systems, improve recycling rates, and reduce landfill waste.

Lastly, implementing AI tools for pollution control offers innovative solutions to mitigate environmental degradation. AI-powered systems can monitor and control emissions from industrial facilities, optimizing processes to reduce air and water pollution. In water treatment plants, AI algorithms can optimize the dosage of chemicals, improve the efficiency of filtration processes, and detect contaminants in real-time. Similarly, in air pollution control, AI can be used to optimize

the operation of scrubbers, filters, and other pollution control devices, reducing emissions of particulate matter, nitrogen oxides, and other harmful pollutants. Furthermore, AI can be used to identify sources of pollution, track pollution plumes, and predict the impacts of pollution on human health and ecosystems. The ability to precisely control and mitigate pollution through AI-driven systems represents a significant advancement in environmental protection, offering cost-effective and efficient solutions to safeguard human and environmental health.

4. The Specific Roles of Artificial Intelligence (AI) Technology in Research and Innovations

Artificial Intelligence (AI) has revolutionized research and innovation across diverse fields, transitioning from a theoretical concept to a powerful and indispensable tool. Its specific roles are manifold, encompassing areas such as data analysis and interpretation, hypothesis generation, experimental design, modeling and simulation, and ultimately, the acceleration of discovery. AI's ability to process and analyze vast datasets far exceeding human capacity, coupled with its capacity to identify intricate patterns and correlations, offers unprecedented opportunities for researchers to unlock new insights and develop groundbreaking innovations. Furthermore, AI's capacity to automate repetitive tasks frees up researchers to focus on higher-level cognitive functions, such as critical thinking and creative problem-solving, ultimately leading to a more efficient and impactful research process. The integration of AI into research workflows is not merely about automation; it is about augmenting human intelligence and fostering a collaborative environment where machines and researchers work synergistically to push the boundaries of knowledge.

One of the most significant contributions of AI in research lies in data analysis and interpretation. Modern research generates enormous quantities of data, often referred to as "big data," which can be overwhelming and difficult to analyze using traditional methods. AI algorithms, particularly machine learning techniques, excel at sifting through these massive datasets, identifying hidden patterns, and extracting meaningful information. For example, in genomics, AI algorithms can analyze vast genomic datasets to identify genes associated with specific diseases [20, 21]. In astronomy, AI can analyze telescope images to detect faint celestial objects and identify patterns in cosmic microwave background radiation [1]. The application of AI in analyzing social media data allows researchers to understand public sentiment, identify emerging trends, and predict societal behaviors [18]. The ability of AI to handle and process complex datasets with speed and accuracy allows researchers to gain insights that would be otherwise impossible, leading to new discoveries and advancements in various fields. Beyond identifying cor-

relations, AI can also assist in causal inference, helping researchers understand the underlying mechanisms driving observed phenomena. This is particularly crucial in fields like medicine and epidemiology, where understanding causal relationships is essential for developing effective interventions.

Beyond data analysis, AI plays a crucial role in hypothesis generation. While traditionally, hypotheses are formulated based on existing knowledge and intuition, AI can assist in identifying novel and potentially fruitful research directions by analyzing existing literature, experimental data, and other relevant information. AI-powered text mining algorithms can analyze scientific publications to identify gaps in knowledge, uncover contradictory findings, and suggest new research questions [2]. For instance, in drug discovery, AI can analyze existing chemical structures and biological activity data to predict the efficacy of new compounds and suggest potential drug candidates that would have been previously overlooked [34]. This AI-driven approach to hypothesis generation can significantly accelerate the research process by focusing researchers' efforts on the most promising avenues of investigation. Furthermore, AI can help researchers avoid confirmation bias by objectively evaluating existing evidence and suggesting alternative explanations. By analyzing data from multiple perspectives, AI can challenge existing assumptions and lead to the development of more robust and comprehensive hypotheses.

AI is also proving invaluable in experimental design. Designing effective experiments is a critical aspect of the scientific method, and AI can assist in optimizing experimental parameters, selecting appropriate controls, and minimizing potential biases. Machine learning algorithms can analyze data from previous experiments to identify factors that significantly influence the outcome and suggest optimal experimental conditions [14]. In fields like materials science, AI can be used to design experiments to synthesize new materials with desired properties [6]. By simulating different reaction conditions and predicting the resulting material characteristics, AI can significantly reduce the number of experiments required, saving time and resources. The use of AI in experimental design extends beyond optimizing parameters; it can also help in selecting the most appropriate experimental methods and techniques. By analyzing data on the performance of different methods in similar contexts, AI can recommend the most effective approach for addressing a specific research question. This can be particularly useful for researchers who are new to a particular field or who are working with complex experimental systems.

Another significant application of AI is in modeling and simulation. AI algorithms can be used to create complex models of physical, biological, and social systems, allowing researchers to simulate different scenarios and predict the outcomes of interventions. In climate science, AI is used to develop sophisticated climate models that can predict the effects of greenhouse gas emissions on global temperatures

and sea levels [31]. In epidemiology, AI models can simulate the spread of infectious diseases and evaluate the effectiveness of different public health interventions [9]. These simulations can provide valuable insights into complex systems and help researchers to make informed decisions. AI-powered simulations also allow researchers to explore scenarios that would be impossible or unethical to study in the real world. For example, AI can be used to simulate the effects of different genetic mutations on human health or to model the behavior of financial markets under extreme conditions. This capability is particularly valuable for understanding complex systems and for predicting the consequences of potential interventions.

Ultimately, the integration of AI across these various roles leads to a significant acceleration of discovery. By automating tasks, analyzing data, generating hypotheses, optimizing experiments, and creating simulations, AI empowers researchers to work more efficiently and effectively. The speed and scale at which AI can process information and generate insights are unprecedented, leading to faster breakthroughs and more rapid advancements in knowledge. The development of new drugs, the discovery of new materials, and the understanding of complex social phenomena are all being accelerated by the application of AI. The collaborative relationship between human researchers and AI systems is fostering a new era of scientific discovery, where machines augment human intelligence and push the boundaries of what is possible. It is important to note that the use of AI in research also presents challenges, including ethical considerations related to data privacy, algorithmic bias, and the potential displacement of human researchers. Addressing these challenges is crucial for ensuring that AI is used responsibly and ethically to advance scientific knowledge and benefit society as a whole.

AI technology plays a multifaceted and transformative role in research and innovation. From its capabilities in analyzing massive datasets and generating novel hypotheses to its contributions in optimizing experimental designs and creating complex simulations, AI is revolutionizing the way research is conducted. The ultimate impact is a significant acceleration of discovery across diverse fields, promising to unlock new insights, develop groundbreaking innovations, and address some of the world's most pressing challenges. As AI technology continues to evolve, its role in research and innovation will only become more prominent, requiring careful consideration of ethical implications and responsible implementation to maximize its benefits for society.

5. Important Sub-Sections of AI Technology and Their Engineering Applications

Artificial Intelligence (AI) has rapidly permeated numerous aspects of modern life, driven by significant advances in computing power, data availability, and algorithmic devel-

opment. Understanding the key subsections of AI technology is crucial to appreciating its potential and limitations, especially when considering its application in specific engineering fields. Prominent areas within AI include machine learning (ML), which focuses on enabling systems to learn from data without explicit programming. This involves algorithms such as supervised learning (e.g., regression, classification), unsupervised learning (e.g., clustering, dimensionality reduction), and reinforcement learning (e.g., training agents through trial and error). Natural Language Processing (NLP) deals with the interaction between computers and human language, enabling tasks like text analysis, machine translation, sentiment analysis, and chatbot development [7]. Computer Vision (CV) equips machines with the ability to "see" and interpret images and videos, facilitating object detection, image recognition, facial recognition, and scene understanding. Robotics integrates AI with physical machines, allowing for autonomous navigation, manipulation, and interaction with the environment. This field leverages ML, CV, and planning algorithms to develop intelligent robots for various applications. Expert Systems, while somewhat older, still hold relevance in specific domains. These systems utilize rule-based reasoning and knowledge bases to emulate the decision-making abilities of human experts in a particular field [7]. These subsections are often intertwined and used in combination to address complex problems.

Engineering, particularly Water Engineering, is increasingly embracing AI to optimize processes, improve efficiency, and enhance decision-making. Water engineering encompasses a broad range of activities related to water resources management, including water supply, wastewater treatment, flood control, irrigation, and hydraulic structures. The integration of AI into these areas holds immense potential for addressing pressing challenges like water scarcity, pollution, and aging infrastructure.

One crucial application lies in water quality monitoring and prediction. Traditional methods for assessing water quality involve manual sampling and laboratory analysis, which can be time-consuming and resource-intensive. AI, specifically ML, can be used to develop predictive models that estimate water quality parameters based on real-time sensor data (e.g., pH, turbidity, dissolved oxygen). These models can identify potential contamination events early on, allowing for timely intervention and preventing widespread pollution [4]. Furthermore, NLP can be used to analyze reports and publications related to water quality issues, extracting key information and identifying trends.

Water distribution network optimization is another significant area. Managing water distribution networks efficiently requires optimizing pumping schedules, minimizing leakage, and maintaining adequate pressure throughout the system. AI algorithms, such as genetic algorithms and neural networks, can be used to develop optimal control strategies that minimize energy consumption, reduce water losses, and improve network reliability [22]. These algorithms can learn from

historical data and adapt to changing demand patterns, ensuring efficient operation even under varying conditions. Furthermore, AI-powered image analysis can be used for automated inspection of pipelines, detecting leaks and corrosion before they lead to major failures.

Wastewater treatment plant (WWTP) optimization benefits greatly from AI-driven solutions. WWTPs are complex systems with numerous interconnected processes and optimizing their performance can be challenging. AI models can be used to predict effluent quality, optimize chemical dosing, and control aeration processes, leading to improved treatment efficiency and reduced operating costs [16]. ML algorithms can also be used to detect anomalies in WWTP operations, identifying potential equipment malfunctions or process upsets before they affect effluent quality. Moreover, NLP can assist in analyzing process data and generating insightful reports for operators.

Flood forecasting and management are critical aspects of water engineering, given the increasing frequency and intensity of extreme weather events. AI can significantly improve the accuracy and timeliness of flood forecasts by integrating data from various sources, including weather models, rainfall sensors, and river gauges [23]. ML algorithms can learn from historical flood events and identify patterns that are difficult for traditional models to capture. Furthermore, AI can be used to optimize the operation of flood control structures, such as dams and levees, minimizing flood damage and protecting vulnerable communities. Computer vision can also be applied for real-time monitoring of floodwaters, providing valuable information for emergency responders.

Hydraulic structure design and analysis can also be enhanced by AI. Traditionally, designing structures like dams and weirs involves complex calculations and simulations. AI can be used to develop surrogate models that approximate the behavior of these structures, allowing for faster and more efficient design optimization. ML algorithms can also be used to analyze large datasets of hydraulic structure performance, identifying potential weaknesses and improving design guidelines.

The integration of AI into Water Engineering is not without its challenges. Data availability and quality are critical for training accurate and reliable AI models. Ensuring data privacy and security is also paramount, especially when dealing with sensitive information related to water infrastructure. Furthermore, the "black box" nature of some AI algorithms can make it difficult for engineers to understand how decisions are being made, which can hinder adoption. Addressing these challenges requires interdisciplinary collaboration between AI experts and water engineers, as well as the development of robust validation and verification procedures. The successful implementation of AI in Water Engineering holds the potential to transform the field, leading to more sustainable, resilient and efficient water resources management practices. As AI technology continues to evolve, its role in addressing the global water challenges will only become more

prominent.

6. The Profound Impact of Artificial Intelligence on the Next Generation and Knowledge Transfer

Artificial Intelligence (AI) is rapidly transforming nearly every facet of our world, and its influence on the next generation and the processes of knowledge transfer is poised to be particularly profound. AI technologies offer unprecedented opportunities to enhance learning, personalize education, accelerate innovation, and ultimately equip future generations with the skills and knowledge necessary to thrive in an increasingly complex and technologically driven world. By automating tasks, personalizing learning experiences, facilitating efficient knowledge sharing, and augmenting human capabilities, AI is revolutionizing how we learn, teach, and disseminate knowledge, creating a future where information is readily accessible, skills are easily acquired, and innovation is continuously fostered.

One of the most significant contributions of AI to the next generation lies in its potential to revolutionize education. Traditional education models often follow a one-size-fits-all approach, failing to cater to the diverse learning styles and paces of individual students. AI-powered educational tools can address this limitation by providing personalized learning experiences tailored to each student's unique needs and abilities. Adaptive learning platforms, for instance, utilize AI algorithms to assess a student's knowledge gaps and learning preferences, and then dynamically adjust the curriculum and delivery methods to optimize learning outcomes. These platforms can identify areas where a student is struggling, provide targeted support and remediation, and offer more challenging material for students who are excelling, ensuring that each student is learning at their optimal pace. Furthermore, AI-powered tutors can provide personalized feedback and guidance, answering questions, offering explanations, and providing encouragement in a way that mimics the experience of having a personal tutor. Companies like Khan Academy are already leveraging AI to personalize learning paths and provide targeted practice exercises, demonstrating the potential of AI to democratize access to high-quality education.

Beyond personalized learning, AI can also enhance the accessibility and inclusivity of education. AI-powered translation tools can break down language barriers, making educational resources available to students from diverse linguistic backgrounds. Text-to-speech and speech-to-text technologies can assist students with disabilities, enabling them to access and interact with educational materials in a way that is accessible and engaging. For example, AI-powered tools can convert written text into spoken words for visually impaired students or transcribe lectures into text for students with hearing impairments. This increased accessibility ensures that all students, regardless of their background or abilities, have

the opportunity to reach their full potential. Moreover, AI can automate many of the administrative tasks associated with education, such as grading assignments and providing feedback, freeing up teachers to focus on more personalized instruction and mentorship. This allows teachers to dedicate more time to understanding the individual needs of their students and providing them with the support they need to succeed.

The impact of AI on knowledge transfer is equally transformative. AI algorithms can efficiently analyze vast amounts of data, identify patterns and insights, and extract relevant information to facilitate knowledge sharing and dissemination. Knowledge management systems powered by AI can automatically organize and categorize information, making it easier for individuals to find the information they need. AI-powered search engines can understand the context of a query and provide more relevant and accurate search results, accelerating the process of knowledge discovery. Furthermore, AI can facilitate collaboration and communication by connecting individuals with relevant expertise and fostering online communities where knowledge can be shared and discussed. Platforms like Stack Overflow use AI to connect programmers with relevant questions and answers, facilitating knowledge sharing within the software development community [28, 29].

AI is also playing a crucial role in preserving and disseminating knowledge from experts and experienced professionals. Expert systems powered by AI can capture the knowledge and decision-making processes of experts in various fields, making this knowledge available to a wider audience. These systems can be used to train new professionals, provide guidance to less experienced individuals, and preserve institutional knowledge that might otherwise be lost due to retirement or turnover. For example, AI-powered systems are being used in healthcare to assist doctors in diagnosing diseases and recommending treatments, leveraging the knowledge of leading medical experts to improve patient care. Similarly, AI is being used in engineering to capture the knowledge of experienced engineers and make it available to younger generations of engineers, ensuring that critical skills and expertise are not lost.

Moreover, AI is enabling the creation of new forms of knowledge and innovation. AI algorithms can analyze data to identify new patterns and relationships that humans might miss, leading to new discoveries and insights. AI-powered tools can automate the process of scientific discovery, accelerating the pace of innovation in fields such as medicine, materials science, and engineering. For example, AI is being used to analyze genomic data to identify new drug targets and develop personalized treatments for diseases. Similarly, AI is being used to design new materials with specific properties, accelerating the development of advanced technologies. This ability to generate new knowledge and accelerate innovation is crucial for addressing the complex challenges facing the next generation, such as climate change, disease, and poverty.

However, the integration of AI into education and knowledge transfer also raises important ethical considerations that must be addressed. Bias in AI algorithms can perpetuate existing inequalities and lead to unfair or discriminatory outcomes. It is crucial to ensure that AI algorithms are trained on diverse and representative datasets and those they are designed to be fair and equitable. Furthermore, the use of AI in education raises concerns about privacy and data security. It is essential to protect student data and ensure that it is used responsibly and ethically. Moreover, the increasing reliance on AI raises concerns about job displacement and the need for workforce retraining. It is crucial to prepare the next generation for the changing job market by providing them with the skills and knowledge they need to adapt to new technologies and thrive in a future where AI is increasingly prevalent. This includes fostering critical thinking skills, creativity, collaboration, and problem-solving abilities, skills that are difficult for AI to replicate.

Artificial Intelligence (AI) has permeated nearly every facet of modern science, engineering, and technological research, revolutionizing how we analyze data, automate processes, and solve complex problems. From medical diagnosis and drug discovery to autonomous vehicles and personalized education, AI's potential seems limitless. However, alongside its transformative capabilities, AI also presents several drawbacks, disadvantages, and areas ripe for further improvement. Understanding these limitations is crucial for responsible development and deployment of AI technologies, ensuring that its potential benefits are realized while mitigating potential risks. This necessitates a critical examination of the ethical, societal, and technical challenges that accompany the increasing integration of AI into our lives.

7. The Drawbacks and Further Improvements of AI Concepts in Modern Research and Innovations

One of the most pressing concerns surrounding AI is the issue of bias and fairness. AI algorithms are trained on historical data, which often reflects existing societal biases related to gender, race, socioeconomic status, and other protected characteristics. If the training data is biased, the resulting AI system will inevitably perpetuate and even amplify these biases, leading to discriminatory outcomes in areas such as loan applications, hiring processes, and even criminal justice. For example, facial recognition systems have been shown to exhibit significantly lower accuracy rates for individuals with darker skin tones, raising serious concerns about their use in law enforcement and security applications [5]. Addressing this requires careful attention to data collection and preprocessing, as well as the development of algorithmic fairness techniques designed to mitigate bias and ensure equitable outcomes across different demographic groups. This includes designing algorithms that are inherently blind to

sensitive attributes or that explicitly account for potential biases in the data. Furthermore, transparency in the AI development process is vital. Algorithmic audits, where independent experts evaluate the fairness and accuracy of AI systems, should become standard practice, particularly in high-stakes applications.

Another significant challenge is the lack of explainability and transparency in many AI systems, particularly deep learning models. These "black box" models can achieve impressive performance, but their internal workings are often opaque, making it difficult to understand why they make certain decisions. This lack of explainability is problematic in several contexts. In medical diagnosis, for instance, a doctor needs to understand the reasoning behind an AI's diagnosis to trust and validate its recommendations [32]. Similarly, in autonomous vehicles, understanding why the AI made a particular driving decision is crucial for investigating accidents and improving safety. The field of Explainable AI (XAI) aims to address this challenge by developing techniques that can provide insights into the decision-making processes of AI systems. These techniques range from visualizing the features that an AI model considers most important to generating natural language explanations of its reasoning. However, XAI is still a relatively nascent field, and significant progress is needed to make AI systems more transparent and understandable, especially for complex deep learning models.

Furthermore, the data dependency and vulnerability to adversarial attacks of AI systems pose significant limitations. Many AI algorithms, especially deep learning models, require massive amounts of labeled data to achieve high performance. Acquiring and labeling such large datasets can be time-consuming, expensive, and sometimes impossible, particularly in domains where data is scarce or sensitive. Moreover, AI systems can be vulnerable to adversarial attacks, where carefully crafted inputs are designed to fool the AI into making incorrect predictions. These attacks can have serious consequences, especially in safety-critical applications such as autonomous vehicles, where an adversarial input could cause the vehicle to malfunction or crash. Robustness against adversarial attacks is an active area of research, with researchers exploring techniques such as adversarial training and defensive distillation to make AI systems more resilient. Data augmentation techniques, which create synthetic data based on existing datasets, can also help to improve the robustness of AI models and reduce their reliance on massive amounts of labeled data.

Another practical disadvantage of current AI systems is their limited generalization and adaptability. Many AI models are highly specialized and perform well only on the specific task for which they were trained. When faced with new or unexpected situations, their performance can degrade significantly. The field of transfer learning aims to address this limitation by developing techniques that allow AI models to transfer knowledge learned from one task to another. However, transfer learning is still a challenging problem, and

significant progress is needed to develop AI systems that can generalize and adapt to new environments and tasks more effectively. This requires developing AI models that can learn more abstract and robust representations of knowledge, rather than relying on brittle and task-specific features. Furthermore, lifelong learning approaches, where AI systems continuously learn and adapt over time, are crucial for developing truly intelligent and versatile machines.

The energy consumption and computational cost of training and running complex AI models, particularly deep learning models, is also a growing concern. Training large language models, for example, can require massive amounts of energy, contributing to carbon emissions and exacerbating climate change. This raises concerns about the sustainability of AI development and the need for more energy-efficient AI algorithms and hardware. Researchers are exploring techniques such as model compression, quantization, and pruning to reduce the size and complexity of AI models, making them more energy-efficient and easier to deploy on resource-constrained devices. Furthermore, the development of specialized AI hardware, such as neuromorphic chips, can also significantly improve the energy efficiency of AI systems [35].

Finally, the potential for job displacement due to automation is a major societal concern. As AI and automation technologies become more sophisticated, they are increasingly capable of performing tasks that were previously done by humans, leading to job losses in various sectors. While some argue that AI will create new jobs as well, the transition may be difficult for many workers, particularly those with limited skills or education. Addressing this challenge requires proactive measures such as investing in education and training programs to prepare workers for the jobs of the future, providing social safety nets to support those who are displaced by automation, and exploring policies such as universal basic income to mitigate the economic consequences of job displacement.

8. The Transformative Power of AI in Modeling, Design, Prediction, and Innovation

Artificial Intelligence (AI) has rapidly emerged as a transformative force across diverse scientific, engineering, and technological domains. Its ability to analyze vast datasets, identify intricate patterns, and generate predictive models has revolutionized how we approach complex problems, design novel solutions, and drive innovation. Modeling, designing, and making predictions are fundamental activities in these fields, and AI tools are increasingly being leveraged to enhance these processes, leading to breakthroughs and efficiencies previously unimaginable. This paradigm shift is driven by the convergence of powerful computing resources, sophisticated algorithms, and the exponential growth of

available data, creating an environment where AI can learn, adapt, and contribute meaningfully to scientific discovery and technological advancement.

One of the most significant impacts of AI is in the realm of scientific modeling. Traditional scientific modeling often relies on simplifying assumptions and computationally intensive simulations to understand complex phenomena. AI, particularly through machine learning (ML), offers alternative approaches that can capture intricate relationships and predict outcomes with remarkable accuracy. For example, in climate science, AI algorithms are being used to develop more accurate climate models that can predict future temperature changes, sea-level rise, and extreme weather events [31]. These AI-powered models can incorporate a wider range of variables and account for non-linear interactions that are difficult to capture with traditional methods. Similarly, in molecular dynamics simulations, AI can accelerate the process of predicting the behavior of molecules by learning from existing simulation data and developing surrogate models that can rapidly estimate the outcomes of new simulations [25]. This allows researchers to explore a wider range of molecular configurations and interactions, leading to the discovery of new materials and drug candidates.

AI is also revolutionizing the design process in engineering disciplines. Traditionally, engineering design involves iterative cycles of prototyping, testing, and refinement, which can be time-consuming and expensive. AI-powered design tools can automate many of these steps, allowing engineers to explore a vast design space and identify optimal solutions more quickly. For instance, in aerospace engineering, AI algorithms are used to optimize the design of aircraft wings by iteratively evaluating different shapes and configurations based on aerodynamic performance criteria [11]. These algorithms can generate designs that are lighter, more fuel-efficient, and more stable than those created using traditional methods. In civil engineering, AI is being used to design more resilient and sustainable infrastructure by optimizing the layout of buildings, roads, and bridges based on factors such as traffic flow, environmental impact, and structural integrity [43]. Generative design, a specific application of AI, leverages algorithms to automatically generate multiple design options based on predefined constraints and objectives, allowing engineers to explore innovative solutions they might not have considered otherwise. This accelerates the design process and potentially leads to more efficient and effective outcomes.

The predictive capabilities of AI are highly valuable in various scientific and technological applications. In healthcare, AI algorithms are being used to predict the onset of diseases, identify patients at high risk of complications, and personalize treatment plans. By analyzing patient data, including medical history, genetic information, and lifestyle factors, AI can identify patterns and predict future health outcomes with greater accuracy than traditional statistical methods. For example, AI-powered image recognition algorithms are being used to detect cancerous tumors in medical

images, such as X-rays and MRI scans, with high sensitivity and specificity [8]. These tools can assist radiologists in making more accurate diagnoses and improve patient outcomes. Furthermore, in industrial settings, predictive maintenance powered by AI is revolutionizing asset management. By analyzing sensor data from machinery and equipment, AI algorithms can predict when a component is likely to fail, allowing for proactive maintenance and minimizing downtime [19]. This optimization greatly improves efficiency and reduces operational costs.

The integration of AI into technological research and innovation is fostering a new era of discovery and development. AI algorithms are being used to analyze large datasets of scientific literature, patents, and research publications to identify emerging trends, promising research areas, and potential breakthroughs [36]. This accelerates the process of knowledge discovery and helps researchers stay abreast of the latest advances in their fields. Furthermore, AI is being used to automate laboratory experiments, analyze data, and generate hypotheses, accelerating the pace of scientific discovery. For example, in drug discovery, AI algorithms are being used to screen vast libraries of chemical compounds and identify potential drug candidates that are likely to bind to specific targets and exhibit therapeutic activity [37]. This process, traditionally time-consuming and expensive, can be significantly accelerated through AI, leading to the faster development of new drugs and therapies. In materials science, AI can predict the properties of new materials before they are even synthesized, guiding the experimental process and accelerating the discovery of new materials with desired characteristics [6].

However, the application of AI in these domains also presents challenges. One of the main challenges is the need for large, high-quality datasets to train AI models effectively. Data scarcity or bias in the training data can lead to inaccurate or unreliable predictions. Another challenge is the interpretability of AI models. Many AI algorithms, particularly deep learning models, are "black boxes," meaning that it is difficult to understand how they arrive at their predictions. This lack of transparency can be a barrier to trust and acceptance, particularly in critical applications such as healthcare and autonomous vehicles. Furthermore, ethical considerations regarding data privacy, algorithmic bias, and the potential displacement of human workers must be carefully addressed. As AI becomes increasingly integrated into scientific, engineering, and technological domains, it is essential to develop robust guidelines and regulations to ensure that AI is used responsibly and ethically [42, 44].

9. Conclusion

Artificial Intelligence holds immense potential to revolutionize education, accelerate knowledge transfer, and empower the next generation. By personalizing learning experiences, enhancing accessibility, facilitating knowledge

sharing, and augmenting human capabilities, AI can create a future where information is readily accessible, skills are easily acquired, and innovation is continuously fostered. However, realizing this potential requires careful consideration of the ethical implications of AI and a commitment to ensuring that AI is used responsibly and equitably to benefit all members of society. By embracing AI's transformative power while addressing its challenges, we can equip the next generation with the knowledge, skills, and values they need to create a better future for themselves and for the world.

AI holds immense promise for transforming science, engineering, and technology, it is crucial to acknowledge and address its limitations and potential drawbacks. Overcoming biases in algorithms, enhancing explainability, ensuring robustness against adversarial attacks, navigating ethical dilemmas, improving generalization capabilities, reducing energy consumption, and mitigating job displacement are all critical challenges that must be addressed to ensure that AI benefits humanity as a whole. By focusing on responsible development, transparency, and ethical considerations, we can harness the power of AI while mitigating its risks and creating a future where AI empowers human potential and contributes to a more just and sustainable world. Further research and innovation in these areas are essential to unlock the full potential of AI and ensure its responsible integration into society.

AI is revolutionizing modeling, design, and prediction across science, engineering, and technological research and innovation. Its ability to analyze vast datasets, identify patterns, and generate predictive models is driving breakthroughs in diverse fields, from climate science to drug discovery. While challenges remain regarding data availability, interpretability, and ethical considerations, the potential benefits of AI are immense. As AI continues to evolve, it is poised to play an increasingly important role in shaping the future of scientific discovery, technological advancement, and human progress. Moving forward, a focus on developing robust AI models, addressing ethical implications, and promoting collaboration between AI experts and domain specialists will be crucial to realizing the full potential of AI in these transformative fields.

Abbreviations

AI	Artificial Intelligence
AGI	Artificial General Intelligence
ML	Machine Learning
NLP	Natural Language Processing
CV	Computer Vision
WWTP	Wastewater Treatment Plant

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Conflicts of Interest

The authors declare no conflicts of interest.

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