ISSN 2776-5229

Reassessing *Al-Khwarizmi*'s Intellectual Legacy in the Era of Industrial Revolution 5.0

Siti Andayani [1*], Ridwan [2], and Budi Susetyo [3]
[1,2,3] Universitas Islam Negeri Prof. K.H. Saifuddin Zuhri Purwokerto
*ennywaluyo12@gmail.com

ARTICLE INFO

Article history
Received April 3, 2026
Revisied May 22, 2026
Accepted June 18, 2026

Keywords: *Al-Khwarizmi*, Intellectual, Scientific Legacy, Revolution 5.0

ABSTRACT

This study aims to examine the intellectual relevance of *Al-Khwarizmi*'s scientific legacy within the framework of Industrial Revolution 5.0, particularly in relation to the development of artificial intelligence, machine learning, digital computation, and the human-centered technology paradigm. Employing a qualitative approach with a library research design, the study integrates a historical-philosophical and conceptual analysis framework to explore the epistemological continuity between classical Islamic scientific thought and contemporary technological systems. Data were collected through documentary research from primary sources, including *Al-Khwarizmi*'s seminal works such as *Al-Kitab al-Mukhtasar fi Hisab al-Jabr wa al-Muqabalah,* as well as secondary literature encompassing peer-reviewed journals, books, and scholarly discussions on Industrial Revolution 5.0, AI ethics, and Islamic philosophy of science, particularly the works of *Syed Muhammad Naquib al-Attas* and *Ismail Raji al-Faruqi.* The data were analyzed using qualitative content analysis and thematic coding to identify key conceptual patterns such as algorithmic reasoning, rational inquiry, knowledge integration, and ethical epistemology, followed by historical-interpretative and comparative analysis to trace their transformation into modern computational paradigms. The findings reveal that *Al-Khwarizmi*'s contributions to algebra, algorithmic thinking, and systematic reasoning constitute a foundational epistemological infrastructure for contemporary digital technologies, including artificial intelligence systems, predictive analytics, and automated decision-making processes. His intellectual legacy shows a strong alignment with the human-centered orientation of Industrial Revolution 5.0, as it inherently emphasizes rationality, structured inquiry, and the pursuit of human welfare. When integrated with the ethical and philosophical *Al-Attas and Al-Faruqi*, *Al-Khwarizmi*'s thought provides a comprehensive framework that bridges scientific innovation and moral responsibility, showing the necessity of embedding ethical governance within modern technological development.

1. INTRODUCTION

The rapid advancement of science and technology in the era of Industrial Revolution 5.0 has significantly transformed various dimensions of human life, ranging from economic activities and industrial production to education, communication, and social interaction (Ziatdinov *et al*., 2024). Unlike previous industrial revolutions that primarily emphasized mechanization, automation, and digitalization, Industrial Revolution 5.0 introduces a new paradigm that places human beings at the center of technological development. This concept, commonly referred to as human-centered technology, seeks to ensure that technological innovation contributes not only to efficiency and productivity but also to human welfare, social inclusion, and sustainable development. Emerging technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), big data analytics,

robotics, and cloud computing are increasingly integrated into everyday life and industrial systems (Chander *et al*., 2022). While these technologies offer numerous opportunities for progress, they also raise important questions concerning ethics, responsibility, and the role of humanity in an increasingly automated world (Jagatheesaperumal *et al*., 2021). The search for such a foundation has encouraged scholars to revisit the intellectual heritage of past civilizations, particularly the contributions of Muslim scientists whose works shaped the development of global scientific knowledge. Among these scholars, *Al-Khwarizmi* occupies a prominent position due to his groundbreaking achievements in mathematics, astronomy, and computational thinking (Elamin, 2024). Living during the Abbasid era, a period often regarded as the golden age of Islamic civilization, *Al-Khwarizmi* contributed significantly to the advancement of scientific inquiry through systematic observation, logical reasoning, and mathematical innovation. His seminal work, *Al-Kitab al-Mukhtasar fi Hisab al-Jabr wa al-Muqabalah*, established the foundations of algebra and introduced structured methods for solving mathematical problems. His contributions to numerical systems and calculation methods facilitated the transmission of scientific knowledge from the Islamic world to Europe.

Al-Khwarizmi's most influential contributions is the development of algorithmic thinking, a concept that has become fundamental to modern computing systems (Saputra, 2023). The term *"algorithm"* itself is derived from the Latinized form of his name, reflecting the profound impact of his intellectual legacy on the evolution of mathematics and computer science (Tatarchenko, 2023). Algorithms provide a systematic sequence of instructions for solving problems, processing information, and generating logical outcomes. In the contemporary digital environment, algorithms constitute the core mechanism behind artificial intelligence, machine learning, data analytics, cybersecurity systems, and automated decision-making processes. Virtually every modern digital platform, from search engines and navigation systems to social media applications and intelligent assistants, relies on algorithmic structures rooted in mathematical logic. This reality shows that many technological innovations associated with Industrial Revolution 5.0 can be traced conceptually to the methodological principles pioneered by *Al-Khwarizmi* (Usmani, 2025). Beyond its technical significance, *Al-Khwarizmi*'s intellectual legacy also reflects a broader epistemological framework characterized by rationality, systematic inquiry, and the integration of knowledge. Islamic scientific tradition historically viewed knowledge as a means of promoting human welfare and societal advancement rather than merely pursuing technical mastery. Scientific investigation was closely linked to ethical responsibility and the pursuit of public benefit. Such an approach resonates strongly with the objectives of Industrial Revolution 5.0, which emphasizes the alignment of technological innovation with human needs and social values. As technological systems become increasingly sophisticated, there is a growing need for intellectual frameworks that encourage responsible innovation and ethical decision-making. *Al-Khwarizmi*'s emphasis on logical reasoning and structured problem-solving offers an important perspective for addressing contemporary challenges associated with technological development. Despite the remarkable benefits generated by technological innovation, Industrial Revolution 5.0 also presents numerous challenges that require critical reflection. The widespread adoption of artificial intelligence and automated systems has raised concerns regarding data privacy, algorithmic bias, digital inequality, labor displacement, and the erosion of human autonomy (Kumar *et al*., 2024). In many cases, technological progress has outpaced the development of ethical frameworks capable of regulating its social consequences. These conditions have generated debates among scholars concerning the necessity of integrating moral values into scientific and technological advancement. Within this discourse, revisiting the contributions of classical Muslim scholars becomes increasingly relevant because their intellectual traditions often emphasized the inseparability of knowledge, ethics, and social responsibility.

Although numerous studies have examined *Al-Khwarizmi*'s contributions to mathematics, algebra, and the history of science, relatively limited attention has been devoted to analyzing the relevance of his intellectual legacy within the context of Industrial Revolution 5.0 (Ridho *et al*., 2026). Existing scholarship generally focuses on his historical role in the development of mathematical sciences without sufficiently exploring the broader implications of his epistemological principles for contemporary technological challenges. Discussions of Industrial Revolution 5.0 often emphasize technological innovation and economic transformation while overlooking the contributions of classical intellectual traditions to human-centered technological development. The epistemological perspective represented by *Al-Khwarizmi* offers a distinctive contribution that differs from many contemporary Western AI ethics frameworks, such as the European Union's AI regulatory approach and the IEEE principles of ethical technology (Elamin, 2024). While these modern frameworks primarily focus on governance mechanisms, transparency, accountability, risk mitigation, and legal compliance, *Al-Khwarizmi's* intellectual tradition is rooted in a more holistic conception of knowledge that integrates scientific inquiry, ethical responsibility, and the pursuit of human welfare within a unified epistemological framework (Elamin, 2024). In the Islamic scientific worldview, knowledge is not regarded as a value-neutral instrument but as a means of promoting justice, public benefit, and moral responsibility (Aulia *et al*., 2025). This integrated perspective provides an important alternative for addressing the ethical limitations of contemporary technological development, where technical innovation often advances more rapidly than moral reflection. Consequently, revisiting *Al-Khwarizmi's* thought is not merely an exercise in historical appreciation but an effort to recover an intellectual model capable of harmonizing scientific progress, ethical governance, and human-centered technological development in the era of Industrial Revolution 5.0. Therefore, this study aims to analyze the relevance of *Al-Khwarizmi*'s thought in the era of Industrial Revolution 5.0 and to explore its potential contribution to the development of ethical, human-centered, and socially responsible technological paradigms.

2. METHODS

This study employs a qualitative approach using a library research design combined with a historical-philosophical and conceptual analysis framework to examine the relevance of *Al-Khwarizmi*'s intellectual legacy in the era of Industrial Revolution 5.0 (Haq, 2025; Putri *et al*., 2025). The study is grounded in the assumption that *Al-Khwarizmi*'s contributions to algebra, algorithmic thinking, and systematic scientific reasoning constitute an important epistemological foundation for understanding contemporary technological developments, particularly artificial intelligence, machine learning, digital computation, and human-centered technology. The primary sources of data consist of *Al-Khwarizmi*'s major works, including *Al-Kitab al-Mukhtasar fi Hisab al-Jabr wa al-Muqabalah*, historical accounts of his scientific contributions, and classical literature discussing his role in the development of mathematics and computational thought. Secondary data were obtained from scholarly journal articles, books, conference proceedings, and contemporary studies related to Industrial Revolution 5.0, artificial intelligence, digital transformation, Islamic philosophy of science, and the works of Muslim scholars such as Syed Muhammad Naquib al-Attas and Ismail Raji al-Faruqi. Data collection was conducted through documentary research by systematically reviewing, selecting, and evaluating relevant academic sources that discuss the intersection between *Al-Khwarizmi*'s intellectual contributions and contemporary technological developments. Data analysis was carried out using qualitative content analysis and thematic analysis to identify conceptual patterns, intellectual connections, and analytical relationships between *Al-Khwarizmi*'s scientific ideas and the characteristics of Industrial Revolution 5.0 (Özden, 2024). The analytical process began with data reduction through the coding of key

concepts such as algebra, algorithmic thinking, rational inquiry, artificial intelligence, human-centered technology, ethical innovation, and knowledge integration. Subsequently, the data were categorized into broader thematic dimensions, including the scientific foundations of algorithmic thinking, the influence of *Al-Khwarizmi* on modern computational systems, the role of ethical values in technological development, and the relevance of Islamic intellectual traditions to contemporary technological challenges. A historical-interpretative approach was employed to examine the evolution of *Al-Khwarizmi*'s ideas from their original historical context to their contemporary applications in digital technologies and intelligent systems. Comparative conceptual analysis was conducted by relating *Al-Khwarizmi*'s intellectual framework to the perspectives of Al-Attas and Al-Faruqi regarding the integration of knowledge, ethics, and human welfare. The findings were then synthesized to formulate an analytical framework how *Al-Khwarizmi*'s intellectual legacy contributes to the development of a human-centered, ethical, and sustainable technological paradigm in the era of Industrial Revolution 5.0. Figure 1 shows research approach in this research.

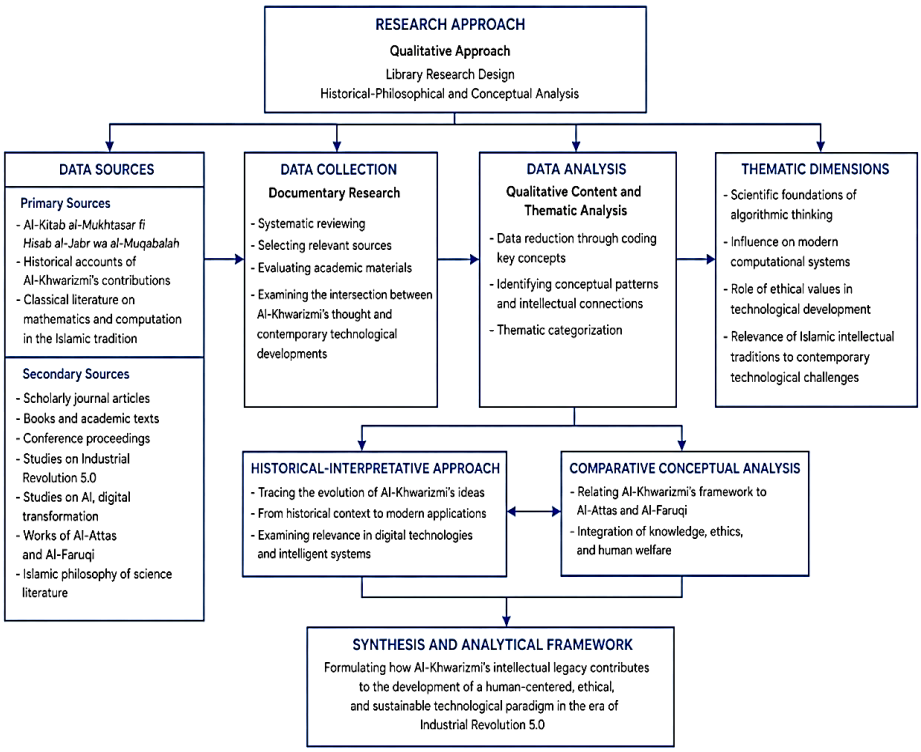

Figure 1. Research Approach

3. RESULTS AND DISCUSSION

RESULTS

3.1 Findings on *Al-Khwarizmi*'s Scientific Legacy

Al-Khwarizmi occupies a central position in the history of science due to his substantial contributions to mathematics, astronomy, and computational reasoning (Saputra, 2023). His intellectual achievements emerged during the *Abbasid* period, a historical era characterized by intensive scientific development and knowledge exchange among various civilizations. Unlike many scholars of his time who primarily preserved earlier knowledge, *Al-Khwarizmi* actively transformed and expanded existing scientific traditions through systematic investigation and logical reasoning. His works showed a commitment to methodological rigor and rational inquiry, which became defining characteristics of scientific scholarship. His contributions extended beyond the

Islamic world and significantly influenced the development of European scientific thought. The enduring relevance of his intellectual legacy illustrates the universal nature of scientific knowledge and its capacity to transcend temporal and geographical boundaries. One of *Al-Khwarizmi*'s most significant contributions was the establishment of algebra as an independent scientific discipline (Faradiba, 2025). Through his monumental work Al-Kitab al-Mukhtasar fi Hisab al-Jabr wa al-Muqabalah, he introduced systematic procedures for solving mathematical equations and numerical problems. This approach represented a major advancement because it transformed mathematical calculation from a collection of practical techniques into a coherent analytical framework. The term *al-jabr*, which later evolved into the modern word "*algebra*," became one of the most influential concepts in the history of mathematics. His methodology emphasized logical structure, sequential reasoning, and problem decomposition, principles that remain essential in contemporary scientific practice. The influence of *Al-Khwarizmi*'s algebra extended far beyond its original historical. Over time, classical algebra evolved into several specialized branches, including linear algebra, abstract algebra, Boolean algebra, and computational algebra (Juraev & Bozorov, 2024). These developments have become indispensable components of contemporary scientific and technological innovation. Modern computer systems rely heavily on algebraic operations to process information, represent data structures, and perform computational analysis. The evolution of algebra shows how foundational scientific concepts can continuously adapt to new intellectual and technological environments.

The term "*algorithm*" originates from the Latinized form of his name, the profound influence of his methodological approach on the development of computational sciences. Algorithmic thinking refers to a structured process of solving problems through a sequence of logical and systematic steps. This concept established an intellectual framework that continues to guide contemporary technological systems. In modern computing, algorithms determine how data are processed, analyzed, and transformed into meaningful outputs. The widespread use of algorithms across digital platforms shows that *Al-Khwarizmi*'s methodological innovations remain deeply embedded within the architecture of modern technology. The significance of algorithmic thinking has become even more evident in the digital era. Contemporary technologies such as artificial intelligence, machine learning, robotics, cloud computing, and big data analytics depend fundamentally on algorithmic processes (Singh, 2025). These technologies operate by identifying patterns, analyzing information, and generating decisions based on structured computational procedures. Although the complexity of modern algorithms differs substantially from early mathematical formulations, their conceptual foundation remains rooted in systematic reasoning and logical problem-solving. This continuity shows the remarkable durability of *Al-Khwarizmi*'s intellectual contributions. It also demonstrates how historical scientific ideas can serve as the basis for transformative technological innovations centuries later. The relationship between algebra and modern computational systems further reinforces the relevance of *Al-Khwarizmi*'s scientific thought. Linear algebra, for example, constitutes one of the most important mathematical foundations of contemporary artificial intelligence. Machine learning models process large quantities of information through matrices, vectors, and linear transformations that originate from algebraic principles. Technologies such as facial recognition systems, autonomous vehicles, predictive analytics, and intelligent recommendation engines all rely on mathematical structures derived from algebraic reasoning. As these technologies become increasingly integrated into everyday life, the foundational importance of *Al-Khwarizmi*'s contributions becomes more apparent. His work continues to influence the mechanisms through which modern societies generate, manage, and utilize digital knowledge. In addition to artificial intelligence, *Al-Khwarizmi*'s intellectual legacy can also be observed in the field of cybersecurity and digital communication (Usmani, 2025). Modern encryption systems depend upon mathematical principles,

including algebraic structures and number theory, to protect information from unauthorized access. Secure financial transactions, digital authentication systems, and blockchain technologies all employ sophisticated computational methods grounded in mathematical logic. These applications shows that the significance of *Al-Khwarizmi*'s work extends beyond theoretical mathematics into practical technological infrastructures. The capacity of contemporary societies to maintain secure digital environments is closely linked to scientific principles that emerged from centuries of mathematical development. Thus, his intellectual influence continues to shape both innovation and security in the digital age. The findings show that *Al-Khwarizmi*'s intellectual legacy can be categorized into several interconnected dimensions, which are algebraic reasoning, algorithmic thinking, problem decomposition, quantitative analysis, interdisciplinary knowledge, precision, and ethical orientation. The synthesis of these findings is showed in Table 1.

Table 1. Synthesis of *Al-Khwarizmi*'s Intellectual Legacy and Its Relevance to Industrial Revolution 5.0

Al-Khwarizmi's Intellectual Legacy	Scientific Principles	Contemporary Technological Applications	Relevance to Industrial Revolution 5.0
Algebra (*al-jabr*)	Introduced systematic methods for solving mathematical problems through logical abstraction, symbolic representation, and structured reasoning.	Computational mathematics, numerical simulations, data modeling, software architecture, and complex engineering systems.	Provides the mathematical foundation required for digital computation, intelligent systems, and data-driven innovation that characterize Industrial Revolution 5.0.
Algorithmic	Developed step-by-step logical procedures for solving problems efficiently and consistently through sequential operations.	Artificial Intelligence (AI), machine learning, deep learning, search engines, recommendation systems, and autonomous technologies.	Serves as the conceptual basis of intelligent automation while supporting human-centered decision-making through adaptive technological systems.
Hindu-Arabic Numerical	Standardized numerical representation and calculation methods, enabling greater accuracy and efficiency in mathematical operations.	Computer programming, digital computation, information processing, database management, and financial technologies.	Facilitates large-scale digital transformation by enabling efficient storage, processing, and transmission of information in modern technological ecosystems.
Linear and Quantitative Reasoning	Emphasized mathematical relationships, proportional analysis, and systematic quantitative problem-solving.	Neural networks, predictive analytics, facial recognition systems, autonomous vehicles, and intelligent robotics.	Supports advanced AI applications that enhance productivity while enabling personalized and human-oriented technological solutions.
Rational and Scientific Reasoning	Promoted evidence-based investigation, logical argumentation, and systematic verification of knowledge.	Scientific research, technological innovation, data science, and evidence-based policymaking.	Encourages responsible innovation and continuous technological advancement grounded in rational analysis and empirical validation.
Interdisciplinary Knowledge	Combined mathematics, astronomy, geography, and practical sciences into a coherent framework of knowledge production.	Computational science, geographic information systems (GIS), interdisciplinary innovation, and integrated digital platforms.	Aligns with Industrial Revolution 5.0's emphasis on collaboration between diverse disciplines to address complex societal and technological challenges.
Precision and	Stressed consistency,	Cybersecurity systems,	Enhances trust, reliability,

Accuracy	exactness, and methodological rigor in scientific calculations and observations.	cryptographic protocols, blockchain technology, secure digital transactions, and information assurance.	and security within increasingly interconnected digital environments and smart societies.
Ethical and Science	Reflected the Islamic intellectual tradition in which scientific advancement is connected to moral responsibility and societal benefit.	Ethical AI governance, responsible innovation frameworks, technology regulation, and sustainable digital transformation policies.	Contributes to the development of technology that balances innovation, ethical accountability, and long-term societal prosperity in the age of intelligent systems.

DISCUSSION

From *Al-Jabr* and *Al-Muqabalah* to Algorithmic Optimization

Al-Khwarizmi's contribution to the history of science extends far beyond his role as the founder of algebra, as his methodology also introduced a systematic approach to problem decomposition that remains highly relevant in contemporary computational thinking (Faradiba, 2025). In *Al-Kitab al-Mukhtasar fi Hisab al-Jabr wa al-Muqabalah*, mathematical problems were not addressed as a single complex entity but were carefully divided into smaller and more manageable components before being reconstructed into a coherent solution. This approach reflects a structured mode of reasoning that emphasizes sequential analysis, logical organization, and methodological precision. Such principles are closely aligned with modern computational frameworks, where complex tasks are decomposed into simpler processes that can be executed systematically through algorithms. In computer science, software engineering, and data science, problem decomposition is recognized as a fundamental strategy for managing complexity and improving analytical efficiency. The enduring relevance of this methodological principle demonstrates that *Al-Khwarizmi*'s intellectual legacy provides not only mathematical foundations but also a conceptual framework for contemporary technological problem-solving (Elamin, 2024). The significance of problem decomposition becomes even more apparent in the context of artificial intelligence and machine learning, where complex computational tasks require structured analytical procedures to generate reliable outcomes (Singh, 2025). Machine learning systems process vast quantities of information by dividing data into distinct variables, features, and computational stages that can be analyzed independently before being integrated into predictive models. This process reflects the same logical structure found in *Al-Khwarizmi*'s approach to mathematical reasoning, where solutions emerge through a sequence of organized and interconnected steps. Rather than relying on intuitive or arbitrary judgments, both classical algebraic reasoning and contemporary computational systems depend upon systematic procedures for identifying, categorizing, and resolving problems. The continued reliance on decomposition strategies within modern digital technologies illustrates the remarkable continuity between classical scientific thought and contemporary computational innovation. Consequently, *Al-Khwarizmi*'s methodological principles can be understood as an early epistemological foundation for the algorithmic structures that characterize modern artificial intelligence and data-driven technologies (Saputra, 2023).

Beyond problem decomposition, the philosophical concepts of *al-jabr* (restoration or completion) and *al-muqabalah* (balancing or equalization) provide a valuable interpretative framework for understanding algorithmic optimization in contemporary machine learning systems. In modern artificial intelligence, predictive models continuously undergo iterative adjustments to minimize errors, improve accuracy, and enhance overall performance. This corrective mechanism resembles the principle of *al-jabr*, in which deficiencies are restored and inaccuracies are

systematically corrected until a more optimal solution is achieved. Similarly, *al-muqabalah* reflects the balancing processes that occur when algorithms seek equilibrium among competing objectives, such as accuracy and fairness, efficiency and transparency, or predictive capability and bias reduction. These optimization procedures are particularly important in addressing contemporary concerns regarding algorithmic bias, accountability, and ethical AI governance (Ryan & Stahl, 2021; Kumar *et al*., 2024). Therefore, the principles of *al-jabr* and *al-muqabalah* may be viewed not merely as historical mathematical techniques but as enduring epistemological concepts that continue to influence the logic of optimization, correction, and balance within modern intelligent technologies (Elamin, 2024).

Al-Khwarizmi and Human-Centered Technology in Industrial Revolution 5.0

Unlike Industrial Revolution 4.0, which primarily emphasized automation, efficiency, and digital transformation, Industrial Revolution 5.0 seeks to establish a more balanced interaction between technological innovation and human well-being (Mourtzis *et al*., 2022). This paradigm promotes the concept of human-centered technology, where technological advancement is directed toward improving quality of life, social welfare, and sustainable development. In this context, technology is no longer viewed solely as a tool for maximizing productivity but also as a means of addressing human needs and societal challenges. Such an orientation requires intellectual foundations that integrate scientific progress with ethical responsibility. The relevance of *Al-Khwarizmi*'s thought to Industrial Revolution 5.0 can be observed through his emphasis on systematic reasoning and structured problem-solving (Elamin, 2024). His scientific methodology was grounded in logical analysis, precision, and the pursuit of practical solutions to human problems. These characteristics remain highly relevant in an era where technological systems increasingly influence decision-making processes across multiple sectors. Artificial intelligence, for instance, relies on algorithmic structures that process information and generate outcomes through systematic computational procedures. Although contemporary technologies are significantly more complex than the mathematical models developed by *Al-Khwarizmi*, they continue to embody the same principles of logical reasoning and methodological organization. The growing importance of artificial intelligence further shows the contemporary relevance of *Al-Khwarizmi*'s intellectual legacy. AI technologies operate through algorithms that analyze large datasets, recognize patterns, and produce predictive or adaptive responses. Applications such as intelligent virtual assistants, recommendation systems, autonomous vehicles, and advanced language models show the central role of algorithmic thinking in contemporary society. These technological innovations reflect the continuation of a scientific tradition that prioritizes structured reasoning and analytical precision. However, the significance of AI extends beyond technical performance because its influence increasingly affects economic, social, and cultural dimensions of human life. Consequently, discussions regarding AI development require not only technical expertise but also ethical and philosophical considerations (Ryan & Stahl, 2021). The most important concerns in Industrial Revolution 5.0 is the ethical challenge generated by rapid technological development. The expansion of artificial intelligence, big data analytics, and automated decision-making systems has created new questions regarding privacy, fairness, accountability, and social justice. Algorithmic bias, misuse of personal data, and unequal access to digital technologies have become significant issues in contemporary society. These challenges show that technological progress alone cannot guarantee positive outcomes for humanity. Instead, innovation must be guided by ethical principles that ensure technology serves the common good. The intellectual tradition represented by *Al-Khwarizmi* emphasizes that knowledge should contribute to societal benefit rather than merely pursuing technical achievement.

Toward an Ethical Epistemology of Technology: Integrating *Al-Khwarizmi, Al-Attas, and Al-Faruqi*

The ethical dimension of scientific knowledge is further reinforced by the thought of *Syed Muhammad Naquib al-Attas*, who argues that knowledge should be integrated with moral and spiritual values (Sholihah *et al*., 2026). According to Al-Attas, the separation of science from ethics can lead to confusion, injustice, and the erosion of human dignity. Scientific advancement without moral guidance may produce technological systems that prioritize efficiency while neglecting human welfare. This concern resonates strongly with contemporary debates surrounding artificial intelligence and digital transformation. Industrial Revolution 5.0 seeks to overcome such limitations by emphasizing the importance of human-centered innovation. Within this framework, *Al-Khwarizmi*'s rational and systematic approach to knowledge can be complemented by *Al-Attas's* ethical perspective to create a more holistic understanding of technological development. A similar perspective is offered by *Ismail Raji al-Faruqi*, who emphasized the integration of scientific knowledge with Islamic values and social responsibility (Sawaluddin *et al*., 2022). *Al-Faruqi* maintained that scientific and technological progress should contribute to justice, human prosperity, and the development of a morally grounded civilization. His concept of the integration of knowledge highlights the need to bridge the gap between technical expertise and ethical responsibility. This idea is highly relevant to Industrial Revolution 5.0 because contemporary technologies increasingly shape social relationships, economic opportunities, and cultural practices. Technological innovation that lacks ethical direction may generate inequality, exclusion, and social fragmentation. Therefore, integrating Al-Faruqi's vision with *Al-Khwarizmi*'s scientific legacy provides a valuable framework for promoting technology that advances both innovation and human well-being. Rather than functioning as separate intellectual perspectives, the ideas of *Al-Khwarizmi*, Al-Attas, and Al-Faruqi can be synthesized into a unified framework of Ethical Epistemology of Technology. Within this framework, *Al-Khwarizmi* provides the methodological foundation through rational inquiry, algorithmic thinking, systematic reasoning, and problem decomposition. Al-Attas contributes the ethical dimension by emphasizing that knowledge must remain inseparable from moral responsibility and human dignity. Meanwhile, Al-Faruqi extends this framework toward societal transformation by stressing the integration of scientific knowledge, justice, public welfare, and civilizational development. Together, these three perspectives establish a holistic paradigm in which technological innovation is evaluated not only according to technical efficiency but also according to ethical accountability and social benefit. This integrated aligns closely with the human-centered orientation of Industrial Revolution 5.0 and offers an alternative to purely technocratic approaches to technological development.

Practical Implications for Technology Governance

The ethical epistemology derived from the synthesis of *Al-Khwarizmi*, Syed Muhammad *Naquib al-Attas,* and Ismail *Raji al-Faruqi* offers important implications for higher education institutions in the era of Industrial Revolution 5.0. Contemporary technological education often prioritizes technical competencies such as programming, data analytics, and system design while providing limited attention to ethical, philosophical, and societal dimensions of knowledge. As a result, future engineers and technology developers may possess strong technical expertise without sufficient awareness of the broader social consequences of technological innovation. The integration of ethical and civilizational perspectives into engineering, computer science, and artificial intelligence curricula is therefore necessary to cultivate a more holistic understanding of technology (Sholihah *et al*., 2026; Sawaluddin *et al*., 2022). Such an educational approach aligns with the intellectual tradition represented by *Al-Khwarizmi*, in which scientific inquiry is closely connected to human welfare and societal advancement rather than merely technical achievement

(Elamin, 2024). By incorporating ethical reasoning, philosophy of science, and social responsibility into technological education, universities can contribute to the development of professionals who are capable of balancing innovation with moral accountability in an increasingly digital world. A second implication concerns the development of artificial intelligence systems through the adoption of an ethical-by-design approach. In many contemporary technological environments, ethical considerations are often introduced only after a system has been developed or deployed, creating challenges related to algorithmic bias, privacy violations, and unintended social consequences (Ryan & Stahl, 2021). Ethical-by-design seeks to address these limitations by embedding ethical principles throughout the entire technological development process, from conceptual design and data collection to implementation and evaluation. This approach resonates with *Al-Khwarizmi*'s emphasis on systematic reasoning, methodological rigor, and responsible problem-solving, where every stage of a process must be logically structured and carefully evaluated (Saputra, 2023). Within this framework, algorithm developers are encouraged to assess technological systems not only in terms of computational efficiency and predictive accuracy but also according to fairness, transparency, accountability, and societal impact (Kumar *et al*., 2024). Such a perspective reflects the human-centered orientation of Industrial Revolution 5.0, which emphasizes that technological advancement should enhance human well-being rather than merely maximize productivity and automation (Mourtzis *et al*., 2022). A third implication relates to the establishment of governance mechanisms that continuously balance technological innovation with societal welfare. The rapid expansion of artificial intelligence, big data analytics, and automated decision-making systems has created complex ethical challenges concerning justice, inclusion, privacy, and public trust (Kumar *et al*., 2024). Drawing upon the philosophical principles of *al-jabr* and *al-muqabalah*, technology governance should incorporate ongoing processes of correction, evaluation, and balancing to ensure that technological systems remain aligned with social and ethical objectives. The principle of *al-jabr* emphasizes the need to identify and rectify deficiencies that emerge within technological systems, while *al-muqabalah* highlights the importance of maintaining equilibrium between competing interests such as innovation and regulation, efficiency and fairness, or economic growth and social responsibility. These principles provide a valuable framework for policymakers, industries, and regulatory institutions seeking to develop sustainable models of digital governance. Consequently, the ethical epistemology formulated through the integration of *Al-Khwarizmi*, Al-Attas, and Al-Faruqi offers a comprehensive foundation for promoting technological development that is innovative, accountable, socially beneficial, and consistent with the human-centered vision of Industrial Revolution 5.0 (Sholihah *et al*., 2026; Sawaluddin *et al*., 2022; Ziatdinov *et al*., 2024).

4. CONCLUSION

Al-Khwarizmi's intellectual legacy remains highly relevant in the era of Industrial Revolution 5.0, particularly in relation to the development of digital technologies, artificial intelligence, machine learning, and data-driven innovation. His contributions to algebra, algorithmic thinking, and systematic scientific reasoning have provided fundamental principles that continue to underpin contemporary computational systems and technological advancement. Beyond their technical significance, *Al-Khwarizmi*'s ideas reflect an intellectual tradition that integrates rational inquiry, ethical responsibility, and human welfare, which closely aligns with the human-centered technology paradigm promoted by Industrial Revolution 5.0. The findings show that modern technological progress can be understood as an extension of the logical and structured methods introduced by *Al-Khwarizmi* centuries ago. The integration of scientific excellence with moral and social values shows the importance of developing technology that serves humanity rather than merely pursuing efficiency and economic gain

5. REFERENCES

Aulia, M. H., Abdussalam, A., Kosasih, A., Ridwan, A. D., Ali, M. M. F., Setiawan, A. G., & Faizin, M. N. (2025). Integrating Science and Technology in Islamic Education through the Tawhid Paradigm. *Mauriduna: Journal of Islamic Studies*, *6*(4), 759-788. https://doi.org/10.37274/mauriduna.v6i4.26

Chander, B., Pal, S., De, D., & Buyya, R. (2022). Artificial intelligence-based internet of things for industry 5.0. In *Artificial intelligence-based internet of things systems* (pp. 3-45). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-87059-1_1

Elamin, M. O. I. (2024). Muhammad ibn Musa *Al-Khwarizmi*: The pioneer of algorithms and his enduring legacy in artificial intelligence. *Journal of Ecohumanism*, *3*(8), 10853-10874. https://doi.org/10.62754/joe.v3i8.5896

Faradiba, S. S. (2025). From the Qur'an to *Al-Khwarizmi*: Traces of Mathematics in Islamic Intellectual Heritage. *Mandalika Mathematics and Educations Journal*, *7*(4), 2182-2191. https://doi.org/10.29303/jm.v7i4.10840

Haq, M. Z. (2025). The Genealogy of Hatred: An Analysis of Traditional Islamic Philosophy in the Contemporary World. *Jaqfi: Jurnal Aqidah Dan Filsafat Islam*, *10*(1), 41-58. https://doi.org/10.15575/jaqfi.v10i1.45743

Jagatheesaperumal, S. K., Rahouti, M., Ahmad, K., Al-Fuqaha, A., & Guizani, M. (2021). The duo of artificial intelligence and big data for industry 4.0: Applications, techniques, challenges, and future research directions. *IEEE Internet of Things Journal*, *9*(15), 12861-12885. https://doi.org/10.1109/JIOT.2021.3139827

Juraev, D. A., & Bozorov, M. N. (2024). The role of algebra and its application in modern sciences. *Engineering Applications*, *3*(1), 59-67.

Kumar, S., Verma, A. K., & Mirza, A. (2024). Digital revolution, artificial intelligence, and ethical challenges. In *Digital transformation, artificial intelligence and society: Opportunities and challenges* (pp. 161-177). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-97-5656-8_11

Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). A Literature Review of the Challenges and Opportunities of the Transition from Industry 4.0 to Society 5.0. *Energies*, *15*(17), 6276. https://doi.org/10.3390/en15176276

Özden, M. (2024). Content and thematic analysis techniques in qualitative research: Purpose, process and features. *Qualitative Inquiry in Education: Theory & Practice*, *2*(1), 64-81. https://doi.org/10.59455/qietp.20

Putri, D. B., Lathifah, L., & Sirozi, M. (2025). The Thoughts of Philosophers of Science and their Application in the World of Education. *Journal of Educational Sciences*, *9*(6), 6245-6273. https://doi.org/10.31258/jes.9.6.p.6245-6273

Ridho, K. A., Fikri, R., & Roza, E. (2026). Mathematics In The Era Of The Abbasid Dynasty: Al-Khawarizmi's Contribution To The Development Of Modern Mathematical Thought In Baghdad 780-850 CE. *Batuthah: Jurnal Sejarah Padaban Islam*, *5*(1), 26-37. https://doi.org/10.38073/batuthah.v5i1.2698

Ryan, M., & Stahl, B. C. (2021). Artificial intelligence ethics guidelines for developers and users: clarifying their content and normative implications. *Journal of Information, Communication and Ethics in Society*, *19*(1), 61-86. https://doi.org/10.1108/JICES-12-2019-0138

Saputra, H. (2023). Al-Khawarizmi: A Muslim scientist who discovered algorithms and their influence in the development of modern computation. *Prevenire: Journal of Multidisciplinary Science*, *2*(2), 84-93. https://doi.org/10.58330/prevenire.v2i2.186

Sawaluddin, S., Harahap, K. S., Rido, I., & Supriono, I. A. (2022). The Islamization of Science and Its Consequences: An Examination of Ismail Raji Al-Faruqi's Ideas. *Jurnal Pendidikan Agama Islam (Journal of Islamic Education Studies)*, *10*(2), 115-128. https://doi.org/10.15642/jpai.2022.10.2.115-128

Sholihah, M., Afifuddin, M. A., & Salik, M. (2026). The Unity of Knowledge in the Perspective of Syed Muhammad Naquib al-Attas: An Epistemological Analysis of Islamic Education. *At-tadzkir: Islamic Education Journal*, *5*(1), 62-81. https://doi.org/10.59373/attadzkir.v5i1.252

Singh, A. (2025). Evolution of Computer Science: A Historical and Technological Overview. *American Journal of Artificial Intelligence and Computing*, *1*(2), 62-86.

Tatarchenko, K. (2023). Algorithm's Cradle: Commemorating *Al-Khwarizmi* in the Soviet History of Mathematics and Cold War Computer Science. *Osiris*, *38*(1), 286-304. https://doi.org/10.1086/725145

Usmani, S. A. A. (2025). From *Al-Khwarizmi*'s Algorithms to Qubits: The Islamic Roots of Modern Quantum Computing. *The Islamic Culture" As-Saqafat-ul Islamia" الثقافة الإسلامية" Research Journal-Sheikh Zayed Islamic Centre, University of Karachi*, *50*(2). https://doi.org/10.58352/tis.v50i2.984

Ziatdinov, R., Atteraya, M. S., & Nabiyev, R. (2024). The fifth industrial revolution as a transformative step towards society 5.0. *Societies*, *14*(2), 19. https://doi.org/10.3390/soc14020019