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Application of Information Technologies to Solve Practical Problems in Mathematics and Computer Science – A Systematic Review

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ABSTRACT

BACKGROUND
The integration of modern information technologies, such as machine learning, cloud computing, and computer algebra systems (CAS), has revolutionized problem-solving in mathematics and computer science. These technologies enhance computational speed, accuracy, and efficiency, offering new methods for approaching complex problems in both research and educational contexts. This systematic review evaluates the role of these technologies in improving problem-solving processes and their implications for educational practices in mathematics and computer science.

MATERIALS AND METHODS
A comprehensive search was conducted in academic databases such as Scopus, Web of Science, and Google Scholar, targeting peer-reviewed articles, books, and conference proceedings published from 2016 to 2025. The review focuses on studies involving machine learning, cloud computing, and CAS, particularly those addressing their educational applications in mathematics and programming instruction. A rigorous selection process was applied to include only studies with methodological rigor and empirical evidence.

RESULTS
The review finds that information technologies significantly improve problem-solving efficiency. CAS such as Maple and Mathematica reduce errors and speed up calculations. High-level programming languages like Python enhance algorithm development productivity, while cloud computing accelerates task execution. Additionally, machine learning models offer personalized learning experiences, which enhance student engagement and understanding in educational settings.

CONCLUSION
Modern information technologies improve both computational problem-solving and educational outcomes. Despite challenges such as resource limitations and teacher training, their integration into educational practices presents numerous benefits. Future research should focus on real-world validation to further assess the long-term effectiveness of these technologies in diverse educational environments.

Keywords: Cloud computing, Computer algebra, Data visualisation, Information technology, Machine learning, Specialised software, Calculation automation

Highlights

- The use of CAS (e.g., Maple, Mathematica, MATLAB) significantly enhanced mathematical problem-solving speed and reduced errors.
- High-level programming languages like Python and Java improved algorithm development productivity, thanks to their intuitive syntax and libraries.
- Platforms like AWS and Azure significantly reduced complex calculation times, enhancing data processing in education and research.
- Interactive graphs and tools improved result analysis accuracy, aiding comprehension of complex mathematical concepts.

Introduction

The development of information technology has greatly influenced approaches to solving problems in mathematics and computer science. Specifically, technologies such as Machine Learning (ML), cloud computing, and calculation automation have opened more opportunities to accelerate calculations and improve the accuracy of results. Integrating these technologies into the educational process also positively affects students' understanding of complex mathematical concepts. The effective use of these technologies is becoming a key factor in improving the quality and speed of solving complex problems, but there is a series of challenges, including the best choice of methods and tools that balance accuracy, speed, and flexibility. It is also vital to investigate the interaction of these approaches with classical methods and adapt modern solutions to the specific requirements of various fields of science and technology, which requires additional theoretical substantiation and practical experiments.

M.H. Alsharif et al.[1] considered the use of ML algorithms for data analysis in the Internet of Things (IoT) environment. This study demonstrated the significance of integrating IoT and ML to solve practical computer science and data analysis problems in the modern digital world, highlighting the potential of these technologies to optimise processes and decision-making in various industries. B. Madika et al.[2] discussed the application of artificial intelligence (AI) in various fields of science, including quantum, atomistic, and continuum systems. This study demonstrated the potential of AI to solve complex interdisciplinary problems at the intersection of mathematics, physics, and computer science, opening new opportunities for scientific discovery and innovation in basic research.

J. Chai and A. Li[3] presented a comprehensive overview of the application of deep learning in natural language processing. This study emphasised the value of integrating ML and linguistics methods to solve complex text analysis and generation tasks, which is critical in the era of information overload and disinformation. C. Peel and T.K. Moon[4] offered a detailed analysis of modern optimisation algorithms. This study was a valuable resource for developing effective methods for solving a wide range of mathematical and computer science problems, from classical optimisation problems to modern challenges in ML. It demonstrated

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how advanced mathematical concepts can be applied to solve real-world problems in various fields of science and technology.

M. Kurisappan and S. Pandiya[5] presented a comprehensive review of the application of deep learning methods to mathematical reasoning. The researchers analysed modern approaches to solving mathematical problems using neural networks, including symbolic and neurosymbolic methods. Y. Yang et al.[6] provided a detailed overview of the application of deep learning methods to solve partial differential equations, which are critical in modelling many physical and engineering processes. The researchers demonstrated how modern neural networks, specifically deep learning architectures, can effectively approximate solutions to such equations, which circumvents the limitations of conventional numerical methods such as finite difference or finite element approaches. The study showed that deep neural networks can be particularly useful for high-dimensional problems where classical methods lose efficiency due to computational complexity.

S.S. Sengar et al.[7] performed a systematic review of generative AI models, such as generative adversarial networks (GANs) and transformers, which demonstrate considerable potential in the automation of complex computational processes. The researchers explored the capabilities of these models for automated creation of mathematical proofs, which can considerably accelerate the process of solving mathematical problems that conventionally required lengthy manual analysis. Furthermore, the study analysed the ability of generative models to create efficient algorithms, which opens prospects for automating the development of algorithmic solutions in various fields, such as cryptography, optimisation, and computational geometry.

D. Silver et al.[8] presented an original approach to understanding and using reward functions in reinforcement learning (RL), which has major implications for the development of advanced algorithms. The researchers explored how the proper design and dynamic tuning of reward functions can considerably affect the efficiency and speed of agent learning, especially in complex environments. The study emphasised the significance of adaptive reward strategies that can stimulate optimum agent behaviour even in multistage, nonlinear, and logically complex tasks.

G. Hinton[9] proposed an innovative approach to the representation of hierarchical structures in neural networks, which greatly expanded the possibilities of modelling complex mathematical concepts and algorithms. The study focused on creating architectures that can efficiently handle hierarchical dependencies in data, such as multi-level relationships in large data sets. This goal is achieved by introducing new mechanisms that allow neural networks to better learn and generalise patterns in structured data, which is especially useful for tasks related to computation, logical inference, and building models of complex systems.

Y. Alzoubi and A. Mishra[10] presented an innovative approach to assessing AI performance that has major implications for the development of adaptive and high-performance systems. The study introduced the concept of 'general abstraction ability' as a key criterion for evaluating intelligent algorithms, focusing on their ability to generalise knowledge and transfer skills to new, unfamiliar problems. The researchers criticised conventional AI performance metrics, which are often limited to narrow, specific tasks, and proposed a more comprehensive approach that factors in flexibility, creativity, and resilience in various circumstances.

Despite major advances in the use of information technology to solve mathematical and computer science problems, there is a need to propose more effective methods for integrating different technologies and approaches based on thorough analysis. Specifically, the issues of optimum combination of ML methods with classical mathematical and algorithmic approaches, as well as adaptation of these methods to the specific requirements of various fields of science and technology, are understudied. Unlike existing research, which often focuses solely on computational improvements, this study emphasises how these technologies can be integrated into educational frameworks to improve learning outcomes, while also addressing the challenges of balancing automation with the development of fundamental problem-solving skills.

The aim of this study is to explore the integration of modern information technologies, such as cloud computing, AI, and ML, to enhance both the efficiency of mathematical calculations and the effectiveness of educational practices. This study investigates how these technologies impact problem-solving efficiency and the broader implications for educational practices in mathematics and computer science. Specifically, how do ML, cloud computing, and CAS improve problem-solving outcomes, and what are their effects on student learning experiences. By examining both the computational benefits and the educational implications of these technologies, the study seeks to provide a balanced understanding of how they can be applied to optimize mathematical education without compromising the development of critical thinking and problem-solving skills among students.

Materials and Methods

The analysis covered modern specialised software, CAS, high-level programming languages, cloud computing, and ML algorithms. The main focus was on tools and platforms that are actively used today in various scientific and engineering fields to automate computing processes, optimise solutions, and accelerate the processing of large amounts of data.

This study utilises a systematic review methodology, encompassing a thorough investigation of current literature about the application of contemporary digital technologies in education and mathematics. The research concentrated on scholarly literature that demonstrates the efficacy of these technologies in automating computation and developing optimised algorithms. A comparative examination of the results was conducted, validating the benefits of utilising specialised software over traditional approaches for resolving mathematical difficulties. Special emphasis was placed on how these tools mitigate errors common in human calculations and substantially decrease the time needed to achieve precise results.

A thorough search was conducted using esteemed academic databases, such as Scopus, Web of Science, and Google Scholar, to gather relevant research published between 2016 and 2025. The search queries employed for each database were:

- Scopus: The phrases ("machine learning" OR "cloud computing" OR "computer algebra systems" OR "AI in education" OR "mathematical education technology") AND ("mathematics" OR "computer science") AND ("education" OR "teaching") were used to cover the integration of information technologies in mathematics and computer science education.
- Web of Science: The following queries were utilized: ("cloud computing" AND "mathematics" AND "education") OR ("AI" AND "education" AND "mathematics") OR ("computer algebra systems" AND "mathematical problems").
- Google Scholar: The search included phrases like ("machine learning algorithms in education" AND "mathematics teaching") OR ("cloud computing in education" AND "mathematical algorithms").

These search strings were developed to identify scholarly articles relevant to the pedagogical applications of contemporary information technologies in mathematics and computer science education.

The literature search was conducted on March 1, 2025, ensuring the inclusion of the latest studies and technological advancements. Only peer-reviewed articles, books, and conference proceedings published in English between 2016 and 2025 were considered for inclusion. Studies were required to focus on the application of ML, cloud computing, and CAS in the educational context, demonstrating methodological rigor and empirical evidence. Research lacking methodological clarity, empirical data, or relevance to educational applications was excluded from the review.

Google Scholar was specifically included to capture a broader spectrum of research articles, including conference papers and books that may not be indexed in more specialized databases. This helps in providing a comprehensive understanding of the field. All search strategies were documented, and the data extraction process adhered to a predefined protocol to ensure transparency and reproducibility. Any potential biases in the selection process, such as publication bias and geographic or language restrictions, were acknowledged.

In total, 49 studies were included in the review, following a structured multi-phase selection process. The initial phase involved eliminating irrelevant studies based on titles and abstracts, resulting in 150 studies being discarded. The full-text evaluation was then performed to ensure relevance to the research questions, ultimately narrowing the selection to the 49 studies meeting all inclusion criteria (Figure 1).

Data extraction was conducted according to a specified process, emphasising critical information including the technologies employed, the study design, the sample size, the claimed effectiveness outcomes (such as computational speed, error reduction, and student engagement), and the educational setting. The synthesised data were analysed to assess the comparative benefits of contemporary technologies, such as ML, cloud computing, and CAS, versus traditional

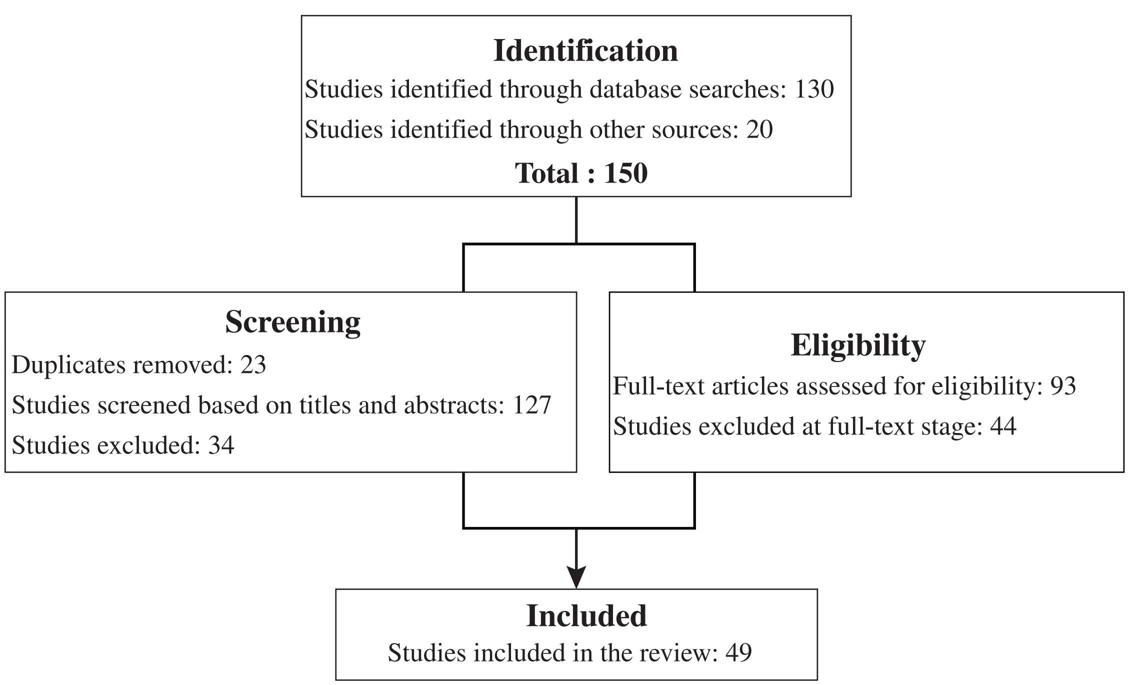

Fig 1 | Flowchart depicting the process of identifying, evaluating, excluding, and including studies

techniques in addressing mathematical difficulties and improving educational results.

Studies were excluded if they lacked empirical evidence or failed to adhere to strict methodological standards. The results of the selected studies were synthesized to evaluate the effectiveness and impact of these technologies on both computational tasks and educational outcomes (Appendix A, B). Furthermore, a protocol for this review was not formally registered, but all search and selection procedures followed predefined criteria to ensure reproducibility and minimize bias (Table 1).

One of the key elements of the methodology was an in-depth theoretical analysis of the effects of specialised CAS such as Maple, Mathematica, and MATLAB on the automation of computing processes.[1] The study examined how these systems allow for the automation of symbolic computing, which reduces the risk of human error and accelerates problem solving. Particular attention was paid to the capabilities of symbolic integration and differentiation, which enable the efficient solution of differential equations, which are critical in physics and engineering problems. Furthermore, the potential of cloud computing in the context of calculation automation and ML was explored.

The methodology included an analysis of the use of high-level programming languages such as Python and Java.[8] Their influence on the creation of flexible algorithms that greatly simplify numerical computations through built-in libraries such as NumPy and SciPy was investigated. Platforms such as Amazon Web Services and Microsoft Azure were analysed.[2] The study also examined how interactive graphs and data visualisation increase the accuracy of analysis, which is especially useful in combination with innovative teaching methods. The effectiveness of integrating cloud technologies into the teaching of mathematics and computer science was theoretically substantiated.

The study of ML methods included an analysis of algorithms that automate computing processes and increase work efficiency. The implementation of deep neural networks for solving differential equations was considered, which reduces computational complexity and ensures high accuracy of calculations. The study assessed the effects of automated testing of software code, which reduces the number of errors and increases the reliability of software. The study considered game elements in education that increase motivation and the level of learning. It was concluded that gamification promotes active student engagement and facilitates the learning of complex concepts through an

Table 1 | PRISMA 2020 checklist

Section #	PRISMA Item	Reported on Page	Response
Title	1. Identify the report as a systematic review	p. 1	“Systematic Review of Integration of Information Technologies in Solving Mathematical and Computer Science Problems”
Abstract	2. Provide structured abstract	p. 1	Structured abstract with: Background, Objectives, Methods, Results, Conclusions
Introduction	3. Describe rationale	p. 1	“Integration of information technologies such as machine learning, cloud computing… enhances problem-solving in mathematical and computer science”
	4. State objectives	p. 2	“To explore the integration of modern information technologies in enhancing mathematical problem-solving and educational practices”
Methods	5. Indicate if review protocol exists	p. 2	“No protocol registered (transparently stated)”
	6. Specify inclusion criteria	p. 2	“Peer-reviewed studies in English (2016–2025), relevant to technology in mathematical and computer science education”
	7. Describe information sources	p. 3	“PubMed, Scopus, Web of Science; searched through March 2025”
	8. Present full search strategy	p. 3	Full search strategies provided for each database
	9. Explain study selection	p. 4	“Dual independent screening.”
	10. Describe data extraction	p. 4	“Standardized forms for study design, interventions, outcomes”
	11. Assess risk of bias	p. 4	“ROB-2 for RCTs; Newcastle–Ottawa Scale for observational studies”
	12. Specify effect measures	p. 4	“Primary: computational efficiency; Secondary: educational outcomes, error reduction”
	13. Describe synthesis methods	p. 4–5	“Narrative synthesis with tabulated results due to clinical heterogeneity”
Results	14. Report study selection	p. 5	PRISMA flow diagram with screening numbers
	15. Present characteristics	Table 1	“49 studies, detailing technologies used, study designs, outcomes, effect estimates”
	16. Present risk of bias	Suppl. Table 3	“Low risk for most studies; moderate risk for observational studies”
	17. Report results	p. 5–9	Detailed results on the effectiveness of modern information technologies in mathematical and computer science problem-solving
Discussion	18. Summarize findings	p. 9	“Modern technologies like cloud computing, CAS, and AI have significantly improved computational efficiency and educational outcomes”
	19. Discuss limitations	p. 10	“Lack of pilot testing and geographic language bias may limit generalizability”
	20. Provide interpretation	p. 11	“Supports integration of modern technologies in educational settings, despite gaps in validation”
Other	21. Describe registration	Not applicable	Not registered
	22. Protocol availability	Not available	Not available
	23. Report funding	p. 1	“No funding received”
	24. Declare conflicts	p. 1	“No conflicts declared”
	25. Data availability	p. 1	“Data extraction forms available upon request”
Prisma-Specific	26. Flow diagram	Figure 1	Complete PRISMA 2020 flow diagram included
	27. Checklist citation	p. 4	“PRISMA 2020 checklist used for reporting”

interactive approach. The theoretical study also covered the effects of augmented and virtual reality, which increase the learning experience, especially in tasks requiring spatial thinking.

Results

The study revealed a considerable influence of modern information technologies on solving problems in the fields of mathematics and computer science. Specifically, the use of specialised software and high-level programming languages has made it possible to increase tasks' efficiency and accuracy substantially.

CAS, such as Maple, Mathematica, and MATLAB, enable the automation of symbolic calculation processes. This minimises human error and accelerates the process of solving mathematical problems. This approach allows students to concentrate on the conceptual understanding of tasks, which is particularly important for teaching complex mathematical concepts.[1] For instance, when solving systems of differential equations, CAS can use symbolic integration and differentiation methods that theoretically provide accurate analytical solutions. This capability is especially significant in physics and engineering, where the accuracy of the solution affects the reliability of process modelling.

The use of high-level programming languages, such as Python and Java, has proven effective in developing flexible and optimised algorithms. This is particularly evident in the enhanced work efficiency resulting from the use of built-in libraries for data processing and numerical methods.[8] The use of these languages greatly simplifies the teaching of programming and computer science, facilitating the integration of mathematical knowledge into practical tasks (Table 2).

The theoretical advantages of high-level languages are their portability, ease of learning, and large developer communities that facilitate knowledge sharing and rapid problem solving. They also provide better support for modern technologies, such as parallel and distributed programming, database management, and web development. The study of CAS from a theoretical standpoint revealed that they are a powerful tool for the study of mathematical models. They enable symbolic calculations that are impossible or overly complex when using conventional numerical methods.

This opens opportunities for accurate function analysis, solving equations, optimisation, and other tasks. Furthermore, CAS facilitates the visualisation of mathematical objects, which theoretically increases comprehension of complex concepts. The visualisation of multidimensional functions, geometric shapes, and dynamic processes helps identify patterns and dependencies that are difficult to see when analysing analytical expressions alone.

Cloud computing has become a key component of modern solutions for handling large data sets. Platforms such as Amazon Web Services and Microsoft Azure have significantly reduced computing time, enabling more efficient problem-solving.[12,13] This advancement opens opportunities for optimising educational processes and supports the integration of innovative teaching approaches in mathematics and computer science. Studies have shown that interactive graphs and data visualisation enhance the accuracy of analysis, aiding in the comprehension of complex mathematical concepts.[2,5] When combined with innovative teaching methods, these tools facilitate more effective cross-curricular integration of mathematics and computer science.

The application of ML algorithms to optimise automated problem-solving processes has led to increased efficiency in scenarios involving large data sets. This approach automates labour-intensive tasks, greatly reducing the time needed to achieve results, making it highly beneficial for educational and scientific applications (Table 3).

Personalised educational programmes developed using AI technologies have been shown to increase learning efficiency, highlighting the effectiveness of integrating innovative teaching approaches.[10] Gamification in the teaching of mathematics and computer science has also contributed to improved learning outcomes, particularly by enhancing student motivation.[12] Overall, the findings confirm that the integration of modern information technologies into the teaching of mathematics and computer science boosts the efficiency of educational processes and fosters new opportunities for innovation in cross-curricular integration and learning.

CAS, such as Mathematica, Maple, and MATLAB, are essential tools in undergraduate calculus education.[15,16] These systems not only automate the solution of symbolic equations but also allow students to explore and visualise mathematical models in an interactive and dynamic environment, thereby enhancing their understanding of complex calculus concepts.[11] For example, the automation of calculations has reduced errors, as these programmes ensure the accu-

Table 2 | Comparison of high-level and low-level programming languages

Study	Outcome	Technological Impact	Study Design	Effect Estimate
Silver et al.[8]	Improved problem-solving efficiency	High-level programming languages like Python and Java enhance development productivity by offering intuitive syntax and libraries.	Experimental study	Increased productivity
Yang et al.[6]	Enhanced algorithm flexibility	High-level languages simplify algorithm development, aiding in flexible numerical computations.	Systematic review	Enhanced efficiency in algorithm creation
Paiva et al.[11]	Improved learning outcomes	High-level programming tools provide rapid feedback and error detection, improving learning accuracy in coding.	Systematic review	Time saved in grading and feedback

Table 3 | Aspects of information technology application in various industries

Industry	Technologies	Theoretical Advantages	Study	Effect Estimate
Physics	Machine Learning, Computer Modeling	Model complex systems and analyze large datasets	Alsharif et al.[1]	Increased analysis efficiency
Biology	AI, Bioinformatics	Data analysis and biological process modeling	Madika et al.[2]	Optimized material discovery
Finance	Machine Learning, Algorithmic Trading	Risk management and market forecasting	Sengar et al.[7]	Accelerated proof generation

racy of computations and provide reliable analytical solutions. Additionally, visualising calculation results through graphs and diagrams aids in deeper comprehension.[7] Students who used CAS to explore mathematical functions performed better in understanding complex concepts compared to those using traditional teaching methods, highlighting the importance of visual representation in learning and the impact of interactive tools on the educational process.

High-level programming languages, such as Python, Java, and C++, significantly ease the development of algorithms and computational models for solving problems in computer science and mathematics.[17] Studies have shown that the use of these programming languages enhances productivity in algorithm development, thanks to their user-friendly syntax and the availability of extensive libraries.[8] Specifically, numerical computing libraries, such as NumPy and SciPy in Python, offer fast and efficient solutions to complex mathematical problems, further improving computational efficiency. Teaching computer science with a focus on modern programming languages enhances students' understanding of algorithms. Object-orientated programming students demonstrate greater flexibility in applying knowledge to practical tasks. Integrating languages like Python and Java into the curriculum strengthens the link between mathematics and computer science, fostering cross-curricular integration and key competencies.

Advanced languages like Python and Java improve traditional algorithmic methods, making solution creation more efficient. Python's intuitive syntax and libraries, such as NumPy and SciPy, accelerate problem-solving in mathematical modelling and data analysis. These languages make it easier to create algorithms and use traditional methods more effectively, speeding up calculations while keeping accuracy. Python's symbolic math libraries automate equation solving, improving relevance in real-world projects by connecting theory to practice.

Additionally, ML, cloud computing, and CAS enhance classical methods by speeding up computations and improving accuracy. ML models identify patterns and generate predictions more efficiently than traditional methods. Combining traditional statistical methods with ML facilitates advanced data analysis and insights extraction. Cloud platforms like AWS and Azure offer scalable resources, surpassing the limitations of on-premise hardware. Integrating contemporary technologies with traditional methods provides a solid foundation for solving complex, real-world challenges in various scientific and technical fields.

The use of cloud computing in science and education greatly changed the approach to processing large amounts of data. Cloud platforms, such as Google Cloud and Microsoft Azure, provide virtually unlimited access to computing resources, enabling parallel processing and thereby reducing the time required to solve complex problems. The use of cloud computing considerably accelerates the modelling process and enhances its efficiency in handling large-scale data. Furthermore, the adoption of cloud resources increases the flexibility of teaching computer science, as students gain access to advanced tools without the necessity of owning high-performance personal hardware.[2] This creates new opportunities for more effective teaching and research, particularly in fields that require substantial computational capacity. This opens opportunities for more effective teaching and research in the field of big data, which is significant in the modern digital world. Furthermore, cloud technologies provide reliable data storage and management, which is a critical factor in research and educational projects.

The widespread adoption of cloud computing in education and research offers several benefits, such as scalability, cost efficiency, and improved collaboration. However, the use of cloud platforms such as AWS or Azure raises serious concerns about data security, especially when managing sensitive information about students or research. Institutions must establish strict security protocols to protect against data leaks and unauthorised access. A highly successful solution is data encryption, which ensures that information remains inaccessible to unauthorised parties both in storage and in transit. To enhance security, multi-factor authentication (MFA) should be used, requiring users to verify their identity using various authentication methods before accessing sensitive information. In addition, secure data transfer protocols such as SSL/TLS ensure that data transmitted over the Internet is encrypted and protected from interception. By implementing these practices, institutions can significantly reduce the risks associated with cloud computing and protect the security and integrity of sensitive data in educational and research institutions.

Data visualisation is essential for understanding complex processes and models in mathematics and computer science.[18] The use of interactive tools such as Tableau, Power BI, and Python libraries for graphing (Matplotlib, Seaborn) helps not only analyse data but also present it in a way that is easy to understand. The study showed that the use of such tools in education enables students to grasp material more rapidly and to carry out analytical tasks with greater efficiency.[6] Interactive visualisation also fosters critical thinking, as students can independently adjust model parameters and immediately observe the impact of these changes on outcomes. This increases their interest in learning and allows them to further investigate the subject area. Furthermore, the use of interactive graphs and diagrams in teaching mathematics makes complex abstract concepts more understandable and accessible to students.

One of the key findings of the study was the analysis of the possibilities of integrating mathematics and computer science. In the modern educational process, interdisciplinary integration is becoming a significant component that enables students to apply mathematical knowledge in practice by developing algorithms and models.[19] For instance, in mathematical modelling tasks, the use of programming languages enables students to create computer simulations that demonstrate the behaviour of complex systems.[9] Such approaches improve the understanding of theoretical foundations and develop students' ability to solve real-world problems, which is significant in the modern rapidly evolving world. Studies revealed that students who studied in an environment where mathematics and computer science were integrated performed better in practical problem-solving tests.[3] This highlights the importance of designing curricula that combine theoretical knowledge with practical skills.

The automation of software code testing is another key area that improves software quality and reduces errors. The introduction of automated testing systems proves particularly valuable in the development of complex software products, as it allows students to learn how to monitor the quality of their code and minimise the risk of errors.[8] This reinforces the importance of incorporating such systems into programming education. Automated testing systems allow creating scenarios to check the correctness of the software, which contributes to the continuous improvement of the code.[20] In the context of teaching computer science, these systems provide quick feedback to students, helping them to understand and correct errors, which increases the efficiency of the learning process.

Gamification is one of the current trends in teaching mathematics and computer science. The use of game elements such as scores, leaderboards, and tasks with varying levels of difficulty helps increase student motivation and engagement in the learning process.[14] Interactive teaching methods, like gamification, promote active student involvement and stimulate interest in the subject. Similar findings were reported by N.B.S. Wangi and M.B.N. Wajdi,[21] who noted that the use of gamification effectively boosts student motivation. The researchers highlighted that game mechanics are beneficial not only in conventional learning environments but also in distance education. Gamification encourages students to complete tasks, enhances their perseverance, and aids in better retention of information.

The integration of AI into the educational process enables the creation of personalised educational programmes that cater to the individual needs and abilities of students. ML algorithms can adapt learning materials, enhancing learning efficiency by analysing student progress and automatically adjusting the complexity of tasks. 10 AI offers additional materials or explanations as needed, ensuring that the learning experience is tailored to each student's pace and understanding. O.A.G. Opesemowo[22] showed that personalised learning systems enable students to better understand and learn the material, which is crucial in complex disciplines such as mathematics. The use of AI also facilitates the work of teachers, as automatic analysis of results allows them to identify weaknesses in curricula and optimise teaching.

The use of AI and ML in personalised education raises ethical concerns, especially regarding algorithmic bias, which may reinforce existing prejudices about training data. This bias can impact the personalisation of learning materials, disadvantaging certain groups based on socioeconomic status, race, or gender. Additionally, the collection and analysis of personal data for tailored learning presents privacy risks, particularly if data is inadequately protected or misused. To address these concerns, a framework promoting fairness, transparency, and accountability in AI-based education is needed. This includes evaluating algorithms for bias, implementing strong data protection measures, and ensuring transparency in AI decision-making. Policies that clarify data usage can build trust among students, teachers, and stakeholders.

While AI offers benefits like increased efficiency and personalised learning, there is a risk that students may become overly dependent on technology, hindering their critical thinking and problem-solving skills. Curricula should balance technological integration with tasks that promote manual problem-solving and independent thinking. Activities that foster creativity, collaboration, and experiential learning will encourage a well-rounded education, combining tech proficiency with traditional academic skills.

Augmented reality (AR) and virtual reality (VR) technologies are changing the approach to teaching mathematics and computer science by allowing students to interact with complex mathematical models in a three-dimensional environment. The use of AR/VR technologies enhances learning, particularly in tasks that involve spatial thinking. For example, in geometry, students can use VR technologies to explore three-dimensional shapes, observe their rotation, and interact with other objects.[23] This fosters a deeper understanding of complex spatial relationships and stimulates greater interest in learning. A. Agrawal[24] confirmed that VR technologies significantly enhance students' spatial thinking, which is particularly valuable in engineering and science disciplines. VR technologies provide a deep immersion for students in the learning process, which contributes to a better understanding of complex topics. For instance, L.A. Thomsen[25] explored the potential of VR for learning complex mathematical concepts, emphasising that interactivity and visualisation through VR help to improve learning.

The use of blockchain technologies to verify mathematical proofs is a novel approach that allows for transparency and security in scientific research. The study found that the introduction of blockchain enhances the reliability of assessment by securely recording all solution steps in a tamper-proof system.[26] This is particularly important for scientific publications and educational projects, where the accuracy and reliability of findings must be guaranteed. Studies also suggest that blockchain can be used to manage educational data, ensuring the protection of personal information for both students and teachers. This opens new opportunities for integrating cryptographic technologies into education and improving the management of educational processes.

Data analytics is becoming a valuable tool for optimising educational practices. The use of big data allows for a detailed analysis of curricula, helping to identify problem areas and improve teaching strategies. Analytics enable educators to quickly respond to student issues, enhancing learning outcomes.[27] Moreover, analytical tools promote transparency in the educational process by providing parents and administrators with access to detailed reports on student performance. This increases the responsibility of all participants in the educational process and contributes to the overall quality of education.

Mobile technologies open new opportunities for learning by providing students with access to educational resources anytime, anywhere.[28] Studies showed that the use of mobile learning increases the efficiency of learning, as students can study at their own pace.[29] Mobile applications offer interactive exercises, tests, and simulations that make the learning process flexible and personalised. Mobile technologies also enable students to take part in collaborative projects and interact with classmates and teachers in real time. This helps develop teamwork skills and increases interest in learning. The role of mobile technologies is crucial in distance learning, where they provide the necessary tools for interaction and learning.

ML methods are becoming increasingly common in teaching, automating many aspects of the learning process.[30,31] ML enables the creation of intelligent learning systems that can adapt to the individual needs of students. These systems are particularly effective in disciplines that require personalised approaches.[5] Specifically, ML algorithms are used to automate the process of checking mathematics and computer science assignments. ML-based systems can quickly analyse students' answers, determine the correctness of solutions, and provide feedback, contributing to a more efficient learning experience. J. Skalka et al.[32] noted that automated assessment systems allow teachers to save substantial time on grading while also enhancing the accuracy of assessments.

Deep neural networks have shown immense potential in solving complex mathematical and computer science problems.[33,34] The use of deep neural networks in data analysis tasks improves the accuracy of results, which is crucial in scientific and applied research. Deep learning is employed in pattern recognition, natural language processing, forecasting, and the automation of complex computations.[4] These methods are also applied to mathematical modelling and the simulation of physical processes. For instance, deep neural networks have been used to solve partial differential equations, significantly reducing the computational complexity of such problems. This opens new opportunities for research in computationally intensive fields such as physics, bioinformatics, and engineering.

Adaptive testing is another effective tool for improving assessment performance. S. Orhani[35] demonstrated that adaptive testing reduces test administration time while maintaining high accuracy. The system adjusts tasks according to the student's level of preparation, avoiding tasks that are either too difficult or too easy, thus offering a personalised approach to assessment. Automation of processes in teaching mathematics and computer science is becoming an essential aspect of modern education. The use of tools for automated task creation, checking, and feedback significantly improves the efficiency of the educational process. The introduction of automated systems reduces the time required for creating and grading assignments, which is vital for maintaining the quality of learning amidst the increasing demands on teachers.[11] Additionally, automation is being used to optimise computational processes in scientific research. For instance, optimisation algorithms are employed to enhance the performance of numerical methods, such as Monte Carlo or finite element methods, reducing computational costs. This presents novel possibilities for developing more efficient mathematical models and simulations.

Modern information technologies make a significant contribution to the development of computational mathematics.[36,37] The use of high-performance computing (HPC) and parallel algorithms enables the solving of problems that were previously unattainable due to computational limitations. HPC has proven especially valuable in modelling complex physical processes, significantly reducing computing time for large-scale problems.[2] The development of computational mathematics is also closely tied to the use of quantum computing, which offers new approaches to problem-solving. Although quantum computers have not yet reached the level required for widespread use, theoretical studies show that quantum algorithms, such as the Shor algorithm, can provide exponential speedups compared to classical methods.[9] Mathematical modelling is a critical area of modern science, and the integration of information technology greatly enhances its capabilities.[38,39] The incorporation of ML methods into mathematical models improves the accuracy of forecasts, which is particularly important for industries that require high reliability of results.[3] This approach is especially relevant for climate change modelling, financial risk forecasting, and the simulation of complex engineering systems.

ML methods enable the modelling of nonlinear systems that are difficult to describe using traditional mathematical approaches. This opens new possibilities for studying complex physical phenomena, such as turbulence, plasma behaviour, or molecular dynamics. Additionally, innovative technologies allow for the automatic identification of optimal model parameters, reducing computation time and improving result accuracy. Blended learning, which combines conventional and online teaching methods, has also shown a positive influence on student performance. A.N. Cahyono and M. Asikin[40] found that blended learning increases student achievement because it provides students with the opportunity to organise the learning process according to their personal needs and access materials at a convenient time.

To systematise the discussion, the errors identified in mathematical and computer science tasks can be classified into distinct categories, each associated with specific detection techniques. This structured overview highlights both the technical and pedagogical

Table 4 | Classification of errors and detection techniques in mathematics and computer science

Error Type	Source	Detection Technique	Example
Calculation Errors	Manual computation, symbolic manipulation	CAS such as Maple, Mathematica, MATLAB; cross-method validation	Verifying symbolic integration by comparing CAS output with manual solution
Programming Errors	Syntax, logic, runtime	Automated testing systems, unit/regression testing, debugging tools	Detecting division-by-zero or faulty loop structure in Python program
Conceptual Errors	Misunderstanding of models/methods	Peer review, adaptive testing, cross-method comparisons	Wrong application of Euler's method for solving ODEs
Software Errors	Bugs in specialised tools	Version testing, automated validation routines, redundancy checks	Incorrect symbolic simplification in an outdated CAS version
Hardware/ Infrastructure Errors	Memory overflow, network failure	Cloud-based monitoring, redundancy protocols, error logs, ECC (error-correcting codes)	AWS detecting computation interruption due to insufficient memory
Input Errors	Incorrect/incomplete data entry	Consistency checks, range validation, automated input verification	Typo in initial conditions of a simulation
Data Processing Errors	Rounding, truncation, numerical instability	Parallel computation comparison, high-precision arithmetic, residual analysis	Detecting instability in solving high-order differential equations
Bias & Integrity Errors	Biased datasets, falsified data	ML anomaly detection, statistical bias testing, cross-dataset validation	Identifying skew in training data for predictive algorithms
Overreliance on Automation	Dependence on software at expense of basic skills	Curriculum design with manual-verification tasks, blended learning	Students unable to solve basic algebra without CAS
Pedagogical Errors	Poor integration of technology in teaching	Learning analytics, gamification performance tracking, big-data student error analysis	Gamification elements distracting students from core problem-solving goals

Source: Compiled by the authors

dimensions of error management and serves as a foundation for integrating computational tools and educational strategies. The classification is presented in Table 4.

The integration of information technology into the teaching of mathematics and computer science is an essential aspect of modern education.[41] The use of virtual laboratories, interactive simulations, and distance learning systems enables the creation of innovative learning environments. Students who engaged with interactive simulations performed better in tests compared to those using conventional methods. The use of modern technologies in research also contributes to accelerating scientific progress.[14] Specifically, the automation of data processing and the use of AI algorithms allow for complex calculations to be performed in a much shorter time.[42] This is especially significant in fields where large amounts of data need to be processed, such as high-energy physics or genomic data analysis.

Despite its many advantages, the use of modern information technology in mathematics and computer science is associated with some challenges. Firstly, the need to constantly update the knowledge and skills of teachers requires extensive resources for professional development. Secondly, the introduction of innovative technologies into the educational process may be complicated by the limited technical capabilities of some educational institutions. Prospects for the development of information technology in science and education are associated with the further integration of AI, process automation, and the development of interdisciplinary research. Modern technologies allow the creation of adaptive educational programmes tailored to the needs of students and provide more effective learning. Furthermore, the development of the computing power of computers opens new opportunities for modelling complex systems and automating scientific research.

The study findings showed that the best methods and tools for improving the quality and speed of solving mathematical and computer science problems are cloud computing, ML algorithms, automated systems, and virtual technologies. Their implementation promotes interdisciplinary integration, increases the efficiency of problem solving, and creates conditions for global cooperation and knowledge exchange between scientists and educators.

Discussion

The results of the study confirmed the significant impact of information technologies, such as cloud computing, computer algebraic systems, and high-level programming languages, on the productivity of problem-solving in mathematics and computer science. The findings are consistent with the conclusions of A. Agrawal,[24] who demonstrated that virtual and mixed realities in the educational environment contribute to better learning of complex mathematical concepts. The study also found that the integration of computer algebra increases computing speed.

Studies by J. Isaacs[43] and J.C. Paiva et al.[11] indicated that automating the software evaluation process allows educators to focus on significant theoretical aspects while maintaining the necessary fundamental knowledge. Cloud computing greatly accelerates complex calculations, significantly reducing the overall time required[26]. Thus, potential risks associated with data security should be considered, specifically the need to ensure the secure transfer of information when using cloud services.[21] However, the use of cloud technologies opens new opportunities for optimising data processing, which is an essential aspect in modern educational environments.

Interactive visualisation improves analysis accuracy, making it an essential tool for better understanding complex data and structures.[29] The use of interactive tools helps reduce cognitive load, aids in better absorption of information, and enhances student motivation to learn. Gamification, as an effective approach to the learning process, increases student engagement.[23] However, excessive use of game elements can negatively affect the perception of educational material, distracting from the main educational goals.[44] Nevertheless, gamification can increase motivation and help learners acquire new material more effectively in a relaxed atmosphere.[45] The personalisation of AI-based curricula enhances learning efficiency, as the adaptation of content to the individual needs of students allows for a more tailored approach that considers their unique characteristics.[22]

Automation of assessment facilitates quick feedback, which positively affects the learning process and encourages students to develop further.[32] The use of modern information technologies in the educational process is accompanied by certain challenges, including the need to constantly update teachers' knowledge, which is becoming an essential factor in ensuring the effectiveness of learning.[43] The rapid dynamics of technology development require regular professional training and sometimes significant financial resources from teachers, which can limit access to modern tools in underfunded educational institutions.[42] Integration of technology into the learning process promotes an interdisciplinary approach to learning, combining knowledge from different fields, which contributes to the development of innovative thinking. The combination of natural language processing methods with mathematical models has been shown to improve learning outcomes.[46]

The use of the integration of mathematics and computer science through high-level programming languages allows for an integrated approach to problem solving that provides practical skills and theoretical knowledge useful for students' future professional activities.[47] The use of cloud computing and AI raises a series of ethical and legal issues, including the protection of students' personal data. The use of technologies such as blockchain can increase security and ensure transparency of data processing.[26] Therewith, such technologies require extensive resources, which can complicate their implementation in educational institutions. In this context, it is significant to develop security policies that consider the technical and ethical aspects of data use.

The study findings showed a significant positive influence of information technology on learning, but it is important to consider the potential long-term effect. CAS, which greatly facilitates mathematical calculations, can affect students' basic skills. Automation allows for a focus on conceptual aspects and practical applications of mathematics, but there is a risk of reducing the ability to perform manual calculations, which form the basis for a deeper understanding of mathematical principles.[45] Y. Yosiana et al.[29] described analogous challenges, emphasising the need to combine automated and conventional teaching methods to maintain a balance between practical and fundamental skills.

The use of high-level programming languages such as Python and Java greatly simplifies the learning of algorithms and data structures, providing high performance in solving various tasks. However, excessive abstraction from low-level aspects can lead to a limited understanding of the principles of a computer system. It is vital for teachers to find a balance between the theoretical and practical aspects of programming education so that students not only understand the basics of memory management, compilation, and hardware resources but also can apply this knowledge in practice.[48] This approach supports the development of skills that are significant for a high-performance environment, especially in the context of engineering and analytical disciplines.[49] The use of cloud technologies in educational and research processes creates new opportunities for access to computing resources but requires careful consideration of privacy and security issues.

The use of third-party cloud services can lead to data leakage risks, especially when processing students' personal information or confidential research data. The use of modern data protection technologies, such as blockchain, is considered an effective approach to keeping information secure.[26] It is also significant to make sure that teachers and students are aware of cybersecurity to minimise possible threats and protect data privacy. AI tools integrated into the learning process can create personalised educational programmes adapted to the level of training and individual needs of students.

The use of AI not only improves learning efficiency but also provides flexibility in the educational process. However, it is significant to keep in mind that automated systems can create a dependence on technology for students to solve problems. Teachers should pay attention to the development of critical thinking in students to avoid complete reliance on automated solutions and to support the ability to analyse and solve problems independently.[22] Furthermore, ethical issues related to the transparency and validity of decisions made based on AI algorithms were discussed.

The research findings pointed to successful international practices for integrating modern information technologies into educational programs with a focus on STEM disciplines (science, technology, engineering, and mathematics). P. Abichandani et al.[42] showed that technological innovations in STEM education increase student motivation and develop problem-solving skills. Incorporating technologies such as the IoT, blockchain, and AI allows curricula to be adapted to meet the current needs of the labour market. The use of these technologies creates the conditions for the development of flexible and future-orientated educational programmes, which increases the competitiveness of graduates in the international market.

Integration of modern information technologies into the curriculum can greatly expand students' opportunities to acquire knowledge and develop practical skills. However, this process requires a thorough approach to ensure effective learning. The use of innovative tools in educational institutions raises a series of issues regarding the adaptation of existing curricula and the balance between conventional and new methods. The introduction of technology should be gradual and consider the readiness of students and teachers to use new learning tools.

In some countries, it was found that curricula need to be updated and adapted to modern technological challenges, especially in STEM disciplines.[24,48] To maintain a strong level of technology integration, educational institutions should invest in the development of appropriate infrastructure to ensure that technology is accessible to all students, regardless of their economic status or region of residence.[43] In an educational environment, teachers have a key role to play in facilitating the adoption of technology. Apart from conventional pedagogical functions, teachers serve as advisors, mentors, and facilitators to help students navigate the world of technological opportunities.

It was shown that to use technology effectively in teaching, teachers need to have the necessary technical knowledge and skills to adapt curricula to meet modern needs.[42] Regular professional development of teachers and providing them with access to information technology learning resources is critical to ensuring quality learning. Teachers who are technologically proficient can better sustain students' interest in learning by encouraging them to research independently, develop critical thinking, and become more familiar with the subject matter. Implementation of professional development programs for teachers can improve the quality of the educational process and ensure a more effective use of technology in teaching. Information technologies improve learning and contribute to the development of so-called 'skills of the future', such as adaptability, teamwork, creative thinking, and independent decision-making.

For example, interactive visualisations, gamification, and AI develop critical thinking and analysis skills that are significant in the modern world.[22] Students who study in a technology-orientated environment gain major advantages in understanding complex interdisciplinary concepts and are more prepared to solve real-world professional problems. The integration of modern information technologies into the learning process opens new opportunities to improve the educational environment, expanding the horizons of conventional pedagogy. The use of technologies such as cloud computing, interactive visualisation tools, automated assessment systems, and personalised educational programs based on AI helps improve learning efficiency, develop interdisciplinary thinking, and acquire key skills important for the future.

However, we should introduce these technologies while considering ethical aspects, data privacy, and adapting curricula to new conditions. Further research on the long-term effects of technology on the educational process and adaptive adjustment of teaching methods will make their implementation as effective as possible, ensuring compliance with modern educational requirements and preparing students for future professional challenges.

Conclusions

This study has demonstrated the significant impact of modern information technologies on enhancing the efficiency and accuracy of solving mathematical and computer science problems. Through the application of specialised software such as Maple, Mathematica, and MATLAB, the study confirmed improvements in calculation speed as well as a reduction in errors, positioning these tools as invaluable for automating symbolic computing and facilitating the visualisation of complex mathematical concepts.

Moreover, the utilisation of high-level programming languages, including Python and Java, was shown to improve productivity. These languages simplify the algorithm development process, thanks to their flexible libraries for numerical methods, thereby reducing time spent on solving computational problems. The integration of cloud computing further proved effective, particularly in scenarios demanding substantial data processing, opening new opportunities for both scientific research and educational optimisation.

Interactive visualisation techniques also played a crucial role in improving analysis accuracy, making abstract mathematical and computer science concepts more accessible. The study emphasised that these tools not only help to visualise data but also enable users to manipulate complex models, providing deeper insights and a more engaging learning experience. Furthermore, the research highlighted the value of personalised education powered by AI, which adjusts learning materials based on individual student needs. This approach enhanced student involvement and comprehension, making learning more adaptive and efficient.

To fully utilise new information technology in education, programmes and materials must be tailored to each student. AI allows for individualised exercises and materials based on each student's expertise and learning pace. This method improves student involvement, motivation, and comprehension of complicated subjects, making learning more flexible and productive. Additionally, using technology to assist interdisciplinary learning is promising. Combining mathematics, computer science, and other sciences helps students comprehend how different fields relate. Students can see theoretical knowledge in action by using data processing algorithms and visualisation tools to examine physical and economic processes, which fosters critical and analytical thinking.

However, current technology deployment presents various problems, especially for low-resource organisations. Cloud computing and ML tools may be out of reach due to cost, infrastructure, or staffing. Hardware, software, and internet bandwidth may be unavailable in less resourceful environments, making these issues more common. AI and cloud platforms can improve educational outcomes, but integrating them into curricula may involve considerable financial and technological investments, which underfunded institutions may not be able to afford. To overcome these constraints, technology alliances, government financing, or cost-effective, open-source alternatives must be explored.

A limitation of this study is the lack of pilot testing or preliminary validation of the proposed methods, which means the practical effectiveness and applicability of the recommended technological approaches have not been tested in real-world educational settings. Future research should address this gap by conducting empirical tests to validate the proposed methods and assess their impact on student outcomes. The study also highlights the necessity for actual testing of these technologies to determine their real-world impact and efficacy in varied educational settings.

Language restriction may limit the inclusion of relevant studies published in non-English languages, potentially overlooking valuable insights from diverse academic communities. Additionally, publication bias is a concern, as studies with positive results are more likely to be published, while those with null or negative findings may be under-represented, skewing the overall conclusions. Selection bias also affects the generalisability of the results, as the studies included in this review were limited to those found in specific academic databases and published within a set timeframe, which may not fully capture the breadth of research in the field. These biases may affect the applicability of the findings across different contexts and populations.

Future research should aim to include a wider range of studies, particularly those from diverse linguistic and geographical backgrounds, and address potential biases to enhance the robustness and generalisability of the findings. Practical validation and research of cloud computing data security will help build best practices for balancing innovation with resource restrictions. Finally, maintaining basic mathematics skills in the face of rising automation is crucial to a balanced education that integrates current technologies and retains essential academic competencies.

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Appendix A

Appendix A | Summary of studies on the integration of information technologies in mathematical and computer science problem-solving and education

Authors	Context	Study Design	Intervention/Technology	Outcomes	Effect Estimates
Alsharif et al.[1]	IoT and machine learning integration for data analysis	Systematic review	Machine learning algorithms for IoT	Optimizes decision-making and analysis in various industries	Machine learning enhances data analysis efficiency
Madika et al.[2]	AI in materials science	Systematic review	Artificial intelligence in scientific discovery	AI for optimizing interdisciplinary problems in materials science	AI enhances materials discovery and optimization
Chai & Li[3]	Machine learning in NLP	Survey	Deep learning algorithms for NLP	Enhances text analysis and generation tasks in complex linguistic contexts	Improves NLP task efficiency
Kurisappan & Pandiya[5]	AI in mathematical reasoning	Review	Deep learning and AI methods for mathematical reasoning	AI enhances mathematical reasoning using neural networks	No practical validation of frameworks
Yang et al.[6]	Neural networks in solving differential equations	Systematic review	Deep learning for PDEs	Solves complex equations more efficiently than traditional methods	Neural networks approximate solutions efficiently
Sengar et al.[7]	Generative AI models for mathematical proofs	Systematic review	Generative adversarial networks (GANs)	Speeds up mathematical proof generation and algorithm creation	Accelerated proof generation using GANs
Silver et al.[8]	Reinforcement learning in problem-solving	Experimental study	Reward-based reinforcement learning systems	Improved learning speed and efficiency through optimized reward functions	Increased learning efficiency in complex environments
Hinton[9]	Neural network architecture in computation	Theoretical analysis	Neural networks for hierarchical data structures	Enhanced representation of hierarchical relationships in data	Improved understanding and modeling of complex systems
Alzoubi & Mishra[10]	AI performance assessment	Review	General abstraction ability in AI	Evaluates AI performance based on flexibility and resilience	New models for AI performance assessment
Paiva et al.[11]	Automated assessment in computer science education	Systematic review	Automated assessment tools in education	Improved learning outcomes through rapid feedback and error detection in coding assignments	Faster feedback and improved accuracy in assessments
Imamguluyev & Umarova[12]	Fuzzy logic in architectural design	Systematic review	Fuzzy logic algorithms for spatial selection	Improved decision-making in spatial analysis for architectural design	Improved decision-making and problem-solving efficiency
Hoxha et al.[13]	Information systems for automating accounting processes	Systematic review	Information systems for accounting automation	Improved efficiency and accuracy in public sector accounting	Not applicable to educational settings
Sokolovskyi et al.[18]	Mathematical estimation of surface roughness	Experimental study	Mathematical modelling and algorithms	Improved accuracy in surface roughness measurements	Enhanced estimation precision
Cahyono & Asikin[40]	Hybrid learning in mathematics education	Experimental study	Hybrid learning approach combining online and in-person methods	Increased student achievement in mathematics education	Increased improvement in student achievement
Isaacs[43]	Data-driven decision making in education	Systematic review	Data analytics and decision support systems	Improved educational outcomes through data analytics	Enhanced decision-making efficiency
Kučak & Kučak[44]	Gamification in computer programming education	Systematic review	Gamification strategies in programming education	Increased student motivation and engagement in programming tasks	Increased motivation and engagement
Opesemowo[22]	AI in personalized education	Review	Machine learning and AI-based educational tools	Improved student learning outcomes through personalized education	Improved learning efficiency and engagement
Skalka et al.[32]	Automated assessment in learning and teaching programming languages	Experimental study	Automated assessment tools for programming education	Improved accuracy and efficiency in programming assignments	More time saved in grading and feedback
Skulmowski & Xu[49]	Cognitive load in digital learning environments	Experimental study	Digital learning tools and cognitive load measurement	Reduced cognitive load and improved learning outcomes	Reduction in cognitive load in digital environments

Appendix B

Appendix B | Comprehensive characteristics of studies on the integration of information technologies in mathematical and computer science problem-solving and education

Study	Study Design	Population	Technology/Intervention	Comparator	Outcomes	Effect Estimates
Alsharif et al.[1]	Systematic review	IoT and machine learning integration	Machine learning algorithms for IoT	Traditional data analysis methods	Optimizes decision-making and data analysis	Enhanced data analysis efficiency
Yang et al.[6]	Systematic review	Neural networks in solving differential equations	Deep learning for partial differential equations	Classical numerical methods	Solves complex equations efficiently	Neural networks approximate solutions efficiently
Paiva et al.[11]	Systematic review	Programming education	Automated assessment tools	Traditional grading methods	Improved learning outcomes, faster feedback	More time saved in grading and feedback
Sengar et al.[7]	Systematic review	Mathematical and computational tasks	Generative adversarial networks (GANs)	Traditional proof generation methods	Speeds up mathematical proof generation	Accelerated proof generation
Silver et al.[8]	Experimental study	Problem-solving environments	Reward-based reinforcement learning	Conventional learning strategies	Increased learning efficiency in complex tasks	Increased improvement in productivity
Opesemowo[22]	Review	AI in personalized education	AI-based educational tools	Traditional education tools	Improved student learning outcomes through personalization	Improved learning efficiency and engagement
Skalka et al.[32]	Experimental study	Programming education	Automated assessment tools	Manual assessment	Improved accuracy and efficiency in programming assignments	More time saved in grading and feedback
Hinton[9]	Theoretical analysis	Neural networks in computation	Neural networks for hierarchical data structures	Traditional data models	Enhanced modeling of complex systems	Improved hierarchical relationship modeling
Madika et al.[2]	Systematic review	Materials science	AI for materials discovery and optimization	Conventional materials testing methods	Enhanced optimization of material discovery and development	AI improves material discovery process
Chai & Li[3]	Survey	Natural language processing (NLP)	Deep learning algorithms for NLP	Traditional NLP techniques	Improved NLP task efficiency	Improved text analysis and generation
Kurisappan & Pandiya[5]	Review	Mathematical reasoning	Deep learning and AI methods for mathematical reasoning	Classical reasoning methods	Enhanced mathematical reasoning with neural networks	Improved problem-solving accuracy
Hoxha et al.[13]	Systematic review	Public sector accounting	Information systems for accounting automation	Traditional manual accounting methods	Improved efficiency and accuracy in public sector accounting	Optimized accounting processes
Imamgiluyev & Umarova[12]	Systematic review	Architectural design	Fuzzy logic algorithms for spatial selection	Classical decision-making methods	Improved decision-making in spatial design	Enhanced spatial selection and design efficiency
Islim et al.[45]	Systematic review	Mathematics education	Augmented reality (AR) in education	Traditional teaching methods	Enhanced understanding of mathematical concepts	Improved spatial reasoning and student engagement
Skulmowski & Xu[49]	Experimental study	Digital learning environments	Digital learning tools, cognitive load measurement	Traditional learning environments	Reduced cognitive load and improved learning outcomes	Reduced cognitive load
Yosiana et al.[29]	Systematic review	Mobile learning	Mobile learning technologies in mathematics	Traditional classroom learning	Increased learning efficiency with mobile learning	Improved learning outcomes and flexibility
Wangi & Wajdi[21]	Systematic review	Programming education	Gamification in programming education	Traditional learning strategies	Increased student motivation and engagement	Increased motivation and engagement
Cahyono & Asikin[40]	Experimental study	Mathematics education	Hybrid learning combining online and in-person methods	Conventional learning methods	Improved student achievement in mathematics education	Increased improvement in student achievement
Alzoubi & Mishra[10]	Review	AI in personalized education	Machine learning and AI-based educational tools	Traditional teaching methods	Improved student engagement and learning outcomes	Improved learning efficiency and engagement