Proceedings of the 11th North American Conference on Industrial Engineering and Operations Management
Milwaukee, Wisconsin., USA, June 9-11, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/NA11.20260382
Published: June 9, 2026

Challenges and Opportunities of AI Tutoring in Operations Research Education

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Abstract

AI tutoring systems ranges from intelligent tutoring systems to large language model–based conversational agents. These systems are rapidly entering STEM classrooms while their implications for math-based courses such as Operations Research (OR) education remain underexplored. OR courses present unique pedagogical challenges including multi-step algorithmic procedures, abstract mathematical structures, and complex modeling tasks that require both conceptual understanding and procedural fluency. This paper investigates the emerging opportunities and challenges of integrating AI tutoring into OR education. The main goal of this paper is to identify how AI tutors can enhance personalized guidance, modeling support, visualization, and scalable feedback and highlight critical risks such as mathematical inaccuracies, over-reliance, explainability gaps, equity concerns, and academic integrity issues. This research also outlines required design principles for effective and trustworthy AI tutoring that match best with requirements and certain specifications of the Operations Research course.

Keywords
Education Systems, AI Tutoring, Operations Research, AI-Enabled Learning

1. Introduction
In recent years, artificial intelligence (AI) and introduction of large language models (LLM) revolutionized many different fields including education. AI tutoring is one of the AI tools introduced that utilize LLM-based tools to guide students by providing on-demand explanations, reasoning steps and feedback to engage learners and enhance their learning experience (Lin et al. 2023). These tools provide personalized access to the tutoring services and offer help in learning difficult courses even math-based courses that require heavy load of reasoning and in-dept learning. Operations Research (OR) is one of such subjects that combines mathematical modeling, algorithmic procedures, and results interpretations. This course creates heavy cognitive load on students who need to understand questions, interpret symbolic representations, connect abstract ideas, and translate between verbal, graphical, and mathematical forms (Dhamini, 2016). In fact, they require to coordinate three different forms of reasoning at once including mathematical reasoning, algorithmic reasoning, and modeling and interpretation reasoning. For example, for modeling tasks they need to identify decision variables, articulate assumptions, translate real-world constraints into math, and interpret optimal solutions.

Majority of the topics covered in the OR course such as modeling, Simplex, duality, transportation, assignment, decision analysis, and so are algorithms with multiple steps that any small error can propagate into the next steps and leads to completely incorrect solutions. During this process, it is very difficult for students to detect such errors and AI tutoring not only can provide step-by -step explanations to complete these tasks but also can identify such errors and support students to complete the tasks. AI tutors that help students during this process

can negatively interrupt the reasoning process of students and prevent learners to get engaged in its conceptual learning. As a result, they will lose their cognitive reasoning abilities to apply the same concepts to real-world problems which is one of the main learning outcomes of such courses. At the same time, integration of such modern educational tools can completely change the course structure and requires instructors to change course presentations and assessment mechanism to ensure academic integrity and achieve the learning outcomes defined for such courses.

Despite rapid usage of artificial intelligence for tutoring various courses, its efficiency in tutoring courses such as operations research are unknown. For efficient usage of such platforms, it is necessary to learn more about its effects on learning, collaboration, and instructor roles. This paper focuses on identifying challenges and opportunities of using AI for tutoring students in operations research course. It also proposes research agenda and design principles for such AI tutoring tool for such courses.

2. Literature Review

In recent years many researchers investigate the requirements for AI tutoring and its effects on learning experience and outcomes of students. In K–12 education specifically, recent syntheses report generally positive effects of intelligent tutoring system (ITS) on learning and performance, particularly in STEM subjects, but also emphasize that these gains are modest and highly dependent on context, implementation quality, and comparison conditions (Létourneau et al. 2025). For example, large-scale meta-analyses provided strong empirical evidence on how AI-driven intelligent tutoring systems consistently improve learning outcomes across educational levels (Ma et al. 2014). In this study, meta-analysis of 107 effect sizes involving over 14,000 learners found that intelligent tutoring significantly outperformed teacher-led whole-class instruction, non-intelligent computer-based instruction, and textbook-based learning depending on comparison conditions.

Similarly, a comprehensive review of 50 controlled evaluations reported a median improvement of 0.66 standard deviations, moving students from the 50th to the 75th percentile when using effective intelligence computer-based tutoring (Kulik and Fletcher, 2016). They also showed that the outcome for adopting this technique varies depending on the alignment between assessments and instructional objectives. Research in higher education also showed similar findings. The meta-analysis of 39 studies showed moderate positive effects across diverse ITS platforms and subject domains, with AI tutors outperforming most instructional alternatives except one-on-one human tutoring [6]. More recent work in K–12 contexts confirmed these benefits, reporting a significant overall effect ($g = .27$) and identifying moderators such as worked examples, intervention duration, and assessment timing as key determinants of ITS effectiveness (Leite et al. 2025). These studies demonstrated that AI-based tutoring reliably enhances learning, though the magnitude of gains depends on implementation quality, instructional alignment, and learner characteristics.

While most work on AI tutoring and intelligent tutoring systems emphasized on the resultant learning gains, a growing body of research warned about negative consequences when students over-rely on AI support (Karamuk, 2025). In general, it was proved that relying on external sources can reduce memory retention and cognitive offloading of students (Sparrow et al., 2011). It was also proved that reliance on external sources for answers may lead to inflated confidence and reduce internal reasoning (Fisher et al. 2015). Similarly, some conceptual papers argued that unchecked use of AI tutors can lead to cognitive atrophy where students outsource core processes such as problem solving, retrieval, and sense-making and weaken learning skills (Leite et al., 2025). The survey on automation bias also showed that humans tend to accept AI suggestions without critically challenging them that eventually this reduces independent judgement of the users (Goddard et al., 2012). Moreover, it was found that AI explanations can discourage independent reasoning and human subjects follow the directions even if they are wrong (Lai and Tan, 2019). It was shown that high levels of AI assistance can reduce cognitive effort and decrease critical thinking of the users and eventually results in over-trust in such tools (Buçinca et al., 2021).

These concerns highlighted the potential risks of using such tools in the education domain that eventually may even undermine the long-term goals of education. Many researchers tried to implement empirical work to investigate the result of such concerns. Recent survey and regression studies on AI use in higher education showed that over-reliance on AI tools is associated with diminished analytical skills, shallow engagement, and increased academic dishonesty, especially when institutional policies and ethical guidance are weak or poorly communicated (Abubakar et al. 2025). Students who frequently outsource tasks such as writing, problem solving, or explanation generation to AI reported lower confidence in their own abilities and greater temptation to avoid learning that eventually reduce their

engagement and motivation levels. At the same time, critical reviews of AI in education highlighted how surveillance-oriented data practices and unclear AI algorithms can reduce trust and emotional well-being especially for more vulnerable learners (Favero et al., 2026). Overall, these studies conclude that risks associated with using AI tutoring are serious and they should be considered when adopting such platforms in education domains and there is a critical need for mindful design, application, and framing such tools in classroom settings instead of overreliance on advantages of such modern tools.

3. Opportunities of AI Tutoring in OR Education

Problem-based learning is an efficient way that can be motivate students as a self-directed learner that explore solutions for their problem. This technique can be also very efficient for learning OR concepts if the instructor designs relevant problem and guide students through steps required to solve this problem using operations research techniques. In problem-based learning of operations research, AI tools can be efficiently applied to assist students to find relevant solutions and techniques and answer their questions and teach them how to implement the techniques (Chai, 2026). Using these modern platforms, can significantly increase student participation in classroom's problem-solving activities by providing accurate guideline and reduce their performance anxiety levels especially during class participation. This can also involve less motivated and marginalized students who never was part of class discussions. Personalized step by step guidance is one of the main opportunities that AI can provide for this course.

AI can also support teachers on the other hand by providing problems that can efficiently address the certain concepts covered in the operations research course. This can need multiple steps of prompting to provide details such as certain features of the problem and required effort from students to complete the tasks. It is also possible to ask generative ai tools to design more challenging questions that might not be able to easily be solved even in case of using the same AI tools by students. Example of such prompt is given below:

"Design an advanced, multi-stage operations research challenge that cannot be solved in a single interaction. The task must require multiple rounds of reasoning, clarification, and iterative refinement with the AI. Requirements for the task you generate:

- It must integrate multiple OR domains (e.g., linear programming, network flows, queuing).
- It must include incomplete information that the student must request in later rounds.
- It must contain at least two hidden modeling pitfalls that students typically overlook (e.g., degeneracy, misleading optimality, dominated branches, tight constraints, infeasible subproblems).
- It must require the student to formulate, analyze, revise, and solve the model across several steps.
- It must include data that appears solvable but reveals deeper complexity only after the student attempts an initial model.
- It must require AI-guided exploration, where the student must ask follow-up questions to obtain missing parameters, clarify assumptions, or request additional constraints.
- It must include a final solution path that the AI will reveal only after the student completes all required steps."

One of the other opportunities that AI tutor can provide is to use these platforms for evaluation of student's solutions and assignments and test and their grading. This platform can easily automate grading procedure by tracing various Simplex steps and tableau. AI tools can also provide group management rules and strategies for complete operation research projects. Students can provide list of their expertise and background, and time availability and AI platform can generate efficient role assignments for teams and provide conflict resolution suggestions when they face with any problem in the team. Students can also provide list of their tasks and activities, and AI can generate their group assignments and tasks. AI tutors can generate various ranges of sample questions for students who would like to practice the covered topics in OR lectures. These questions can be generated by providing clear prompts on number of steps and efforts required to complete the task. Figure 1 shows information flow of AI tutoring mechanism (Figure 1).

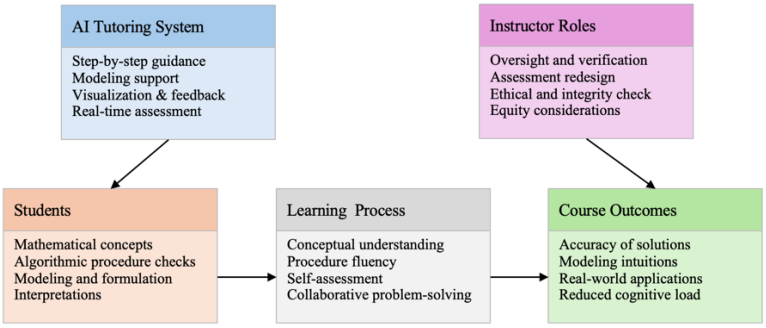

Figure 1. Information flow of AI tutoring mechanism

4. Effective Design Principals

Effective design of an AI tutoring mechanism will require certain capabilities and features which are explained in this section.

4.1. Step-by-Step Explanations

During tutoring process of operations research courses, the tutor requires to clearly explain steps and reason behind implementing and choosing them. Majority of the topics covered in the Operation Research Course required multiple steps of reasoning and calculations that not understanding one step can cause misunderstanding in other downstream steps. Therefore, the AI tutor should provide clear explanations of each step that can be checked and verified by students for their better understanding of the concept. For example, in mathematical modeling of the students, it can provide list of the steps required for modeling including data collection, identifying model elements, and writing constraints and related equations. Each one of the steps require clear explanations for students how to navigate the question and find the related information and implement the steps to complete the task. Similarly, students working on Simplex problems will need to have a clear reasoning behind each step of simplex building and pivoting procedure. They should also understand how they can verify their processes and what exactly will signal problems and mistake when solving certain problems.

4.2 Step Verifiable

Majority of operations research problems require many calculations that any error and mistake in one step can propagate in the later calculations. AI tutor can also play a role of a tutoring checking all these steps to find any mistake in calculations and missing certain steps and requirements. It can also check if any of the assumptions are not violated when modeling or if certain constraints are feasible or causing infeasible solutions. Other examples for such checks can be checking stability conditions in queuing models, branch and bounding rules and requirements, or checking complementary slackness in each step of the Simplex tabluea. Some logical rules during modeling such as flow conservation in network modeling or resource allocations can be also checked and verified by AI tutors. Symbolic consistencies in using notations for variables, parameters, and indices can be also checked and verified by AI tutoring mechanism.

4.3 Conceptual Understanding

In OR problems students need to reason about structure, meaning, assumptions, feasibility, and interpretations of their solutions instead of just computing simple steps and completing the task. Conceptual reasoning plays very critical role in understanding and formulating mathematical modeling and other similar problems in operations research course. Moreover, students usually require the concepts learnt in one problem to different problems that conceptual understanding of the concepts can help them to generalize their learning for solving new problems. Moreover, interpreting results will be almost impossible without conceptual understanding the problem, its requirements, and logic behind the steps.

The designed AI tutor should be able to assist with conceptual learning of the course. The first step in this path will be evaluating students understanding level by asking questions about goal and intention of the method, the importance of the problem and solution sections, and related interpretations. If any shortcoming is detected, the AI tutor should proceed with providing more targeted explanations and support to help them understand underlying ideas, structures, and meanings behind each step. In some cases, even if students start explaining certain technique in depth, after a

while he/she may only proceed with implementing steps without in-dept understanding of the concepts, assumptions, and aspects. In this stage, any errors even in procedural level can reveal potential conceptual gaps in students understanding. These conceptual gaps may exist in student learning even if they can solve questions correctly. The AI agent can identify these shortcomings by asking students about meaning, interpretations, and insights about the solved problem. For example, it can ask student how the solution is expected to change if certain parameter is revised. Interpretations can be considered as strongest signs to show the dept of conceptual understanding of the concept. AI should be able to detect when a student needs conceptual scaffolding versus procedural guidance and adapt explanations accordingly.

4.4. Modeling Scaffolding

The main part of the OR education is related to mathematical modeling of the problem. AI tutors should be able to scaffold modeling process as a structural cognitive process. The main elements of the modeling include assumptions, variables, constraints, and objective function. Students may fail in the modeling procedure in choosing correct and relevant decision variables, ignore certain constraints, mistakes in identifying correct objective functions, or misrepresent uncertainties. Identifying decision variables are the most challenging part of the modeling and students usually have very difficult time to define them clearly. AI tutor can assist students in this stage by providing helpful hints and explanations. Identifying assumptions is also very critical for correct modeling of the problem. AI tutors can clearly identify misunderstanding of the assumptions before starting problem solving to make sure students move in the right direction for mathematical modeling. The other challenge during modeling process is to identify the constraints and students may not be able to correctly collect the required information and present them as constraints.

AI tutors can guide students during constraint building process by asking the following questions:

- What limits the decision?
- What must be conserved?
- What must be satisfied exactly?
- What must be satisfied at least/at most?

Similarly, objective functions can be easily identified by asking similar type of the questions. Part of these questions are listed below:

- What are we trying to optimize?
- Is this a cost or profit?
- Does each variable contribute linearly?
- Are there penalties or bonuses?

Justifying variable selection, constraint, and objectives at this stage can signal potential conceptual gaps.

4.5. Adaptive Hinting

Adaptive hinting is one of the most important functionalities that AI tutor can provide to adjust student's conceptual level. Adaptive hinting is different from step verifications explained in the previous sections. Step verification is implemented after student attempt and check its correctness, while adaptive hinting is implemented before or during a step to support student's learning by providing conceptual and procedural guidance. These hints can be provided by AI tutor one any of the diagnostic signals is detected. Hesitation and pauses, conceptual error and student misunderstanding, procedural error and calculation mistake, or failure after multiple trials can be considered as a guiding signal to initiate AI hinting. AI tutor can provide various range of comments and hints to ignite student thinking and assist him/her to complete the task. Below is the list of four levels of hints that a AI tutor can provide:

- Light conceptual prompt
- Strategic hint
- Procedural hint
- Full explanations

The first level in providing hints is implemented to nudge the student to recall the concept. Questions motivating student to check previous steps can be helpful in this level. During strategic hint level, AI tutor guides the student toward the correct approach instead of correct final answer. For example, it can provide instructions such as this sentence in the assignment problems: "Try reducing the smallest value in each row first.". In next level of providing hint, the AI tutor helps student to perform next step correctly. This level is like the previous level, but AI tutor provides more details about the next step and how student needs to proceed. In last step of providing hints, the AI tutor provides

full explanation about the method and concepts behind it. This level of hinting is triggered only if student fails after multiple trials. Adaptive hinting in all four levels can prevent any possible conceptual drift, support metacognition, and improve interpretation skills and long-term retentions of the concept. Examples of such hints are listed below:

- "Before choosing the entering variable, think about what the reduced cost represents. Which variable would most improve the objective if it entered the basis, and why does that improvement matter conceptually rather than procedurally?"
- "Instead of computing the dual mechanically, ask yourself: What resource or constraint in the primal is this dual variable measuring? Understanding that meaning will help you construct the dual structure correctly."
- "When you see a negative opportunity cost, think about what it implies: Why does assigning one unit to this cell reduce total cost? Focus on the economic intuition before performing the cycle."

4.6. Collaboration-Aware AI Tutoring

Team projects is one of the main elements of the Operations Research courses. AI tutors need to be designed in a way that can support group student work. Capabilities such as role assignments, prompting peer explanations, and conflict mediation in AI tutoring can support collaborative learning of the students in each team. Once students divide roles for modeling, evaluating, explaining concepts, and solving AI tutor can provided targeted hints and comments for each team member. It can be also used when students disagree on some concepts and steps and need additional outside checks and approvals.

4.7. Control Analytics and Transparency

The main goal of using AI tutors should be to provide additional support for students instead of replacing instructors. In fact, AI tutors should complete and assist instructors to ensure students learn the materials covered in the lectures. To support students in more human center way and provide a robust and adaptive course content, instructors should be able to see what types of the support is provided for students. Analytics related to common mistakes and problems can help instructors to receive additional feedback to adjust course content and provide more targeted learning platform. Instructors must remain the pedagogical authority and ensure academic integrity. To increase control of instructors and provide require intervention steps, AI tutors must provide traceable reasoning maps, history of explanations, and other analytics to ensure instructors it does not mislead student and properly guide conceptual learning of students. In fact, AI tutors should be in form of human in the loop AI and instructors should be able to verify correctness of outputs provided by AI.

4.8. Equity and accessibility

The AI tutor should be able to adjust its hints and explanations based on the unique features of the students. If not, students will be discouraged and stopped using it for other problems. It should support three pillars of Universal Design for Learning including multiple means of representation, multiple means of action and expression, and multiple means of engagement. This is especially important for Operations research course that overwhelms working memory capacity with large simplex tables, multiple rounds of updates in some network models, switching between two representations in certain problems, and juggling assumptions, variables, and constraints during modeling a problem. Improper design of this assistant can lead to increase inequalities in learning and education systems. Adaptive pacing and load balancing is one of the important features that need to be included in this mechanism to ensure that pace of explanations and assistance and their difficulty and cognitive load are presented consistent with student background and learning capabilities. It should be able to provide multi-modal support in forms of text, symbolic math equations, tables, graphs, animations and so on to ensure that it benefits wide range of audience types of students. The content provided by these tutors should be also accessible to support students with disabilities and special requirements.

4.9. Assessment Alignment

The hints, explanations, and other forms of supports provided by AI tutors should be completely aligned by skills, reasoning, and learning outcomes that instructors will evaluate using tests and other assessment means. Otherwise, it will just provide guidance for method completion instead of reinforcing certain skills and capabilities. This is important for Operations Research course because it rarely assess memorizing steps and methods and mostly relies on evaluating students in modeling, result interpretation, justification, conceptual reasoning, and transferring what was learnt to new scenarios and problems. So any form of verification, evaluation, and hinting should be consistent with learning outcomes of the course. On the other hand, ai tutors should avoid providing full solutions that undermines assessment integrity and should focus on asking guiding questions, providing partial targeted hints, require justifications and interpretations for student solution to keep learning aligned with assessment goals.

5. Challenges and Risks

Although AI tutors provide wide range of opportunities and capabilities for students and instructors, it also may create new challenges and risks that need to be considered before implementation of such techniques in classroom settings. Generative AI-enabled tools rely on large language models time to time may create irrelevant and inaccurate outputs which is known as hallucination. This is more challenging for application of such techniques for STEM fields especially Operations Research course that includes mathematical multi-step calculations. OR algorithms such as Simplex, Hungarian technique, and network models require multiple rounds of calculations that any mistake in one step can propagate to the next steps. Students using AI tutors rely on its comments and guideline provided and any failure in one step, even if it is as small as identifying wrong entering variable in Simplex can ruin the entire procedure and cause incorrect teaching of students or reducing their trust in using these platforms.

Full reliance on the AI tutor is another challenge in using such systems that can hinder cognitive efforts and in dept learning of the students. Once students notice the power and capabilities of such systems, they may get lazy to complete the calculations and refuse to understand the underlying logic and concepts behind procedures. Inappropriate using of these tools can reduce conceptual understanding and long-term retention of the covered concepts in the class and decrease their ability to apply those concepts for new problems. This is one of the major challenges especially in mathematical modeling where students require deep conceptual understanding and reasoning to identify objectives, variables, constraints and other assumptions of the model. This issue eventually can undermine ultimate learning outcomes of the course by failure of students to develop modeling intuition to apply same techniques for real-world problems.

Majority of existing AI-enabled tools provide correct answers for problems but fail to explain the reasoning behinds calculations. This can undermine some of the required design considerations discussed in the previous section. Proving hints and conceptual comments and justifications require transparent reasoning for each step and lack of ai explainability can reduce efficiency of these techniques and their practical applications. Students must understand the logic behind operations to be able to evaluate their own approach and learn the concepts in depth.

The most important obstacle to apply a AI tutors is concerns related to academic integrity and complexity of identifying legitimate AI supported learning and unauthorized outcomes. It is very likely that students use AI to complete assignments without understanding of the concepts and even techniques. This challenge can make assessments on assignments invalid. Although designing AI tutors relying on assessment-aligned support and providing conceptual hints and explanations can reduce this issue and some of the previously mentioned challenges, it still cannot guarantee to eliminate the potentials of these risks and challenges in the educational settings.

This is a common understanding that introducing AI tutors can remove or reduce workload of the instructors, while the experimental results show that it only transforms the nature of the workload of instructors. In case of using AI tutoring in the system, the instructors need to monitor and verify the outputs of these systems and ensure legitimate usage of such platforms. They also require redesigning majority of their course contents and assignments to prevent any AI misuse and ensure that assessments stay valid for measuring conceptual and procedural understanding of the students. This redesign should include more interpretation and justification type questions and concepts instead of simple multi-step solutions. In fact, instructors will require new trainings and new pedagogical strategies to be able to orchestrate AI- supported learning in the classroom.

Using AI-supported tools can also widen achievement gaps in which students with stronger prior knowledge and digital familiarity and more technology access can benefit more from these tools. This can create inequalities in the classroom and discouragement in some of the students. Additionally, not all institutes can provide technological resources, and this can create structural inequalities between students with different levels of technology resource availability. Similarly, not all institutions have access to the AI resources, and this will impact learning levels of the students taking these courses in different institutions.

6. BCOR Analysis

To summarize different aspects of AI tutoring, BCOR technique is applied to examine benefits, costs, opportunities, and risks of adopting AI tutoring in math-based courses such as OR. This technique helps us to get a balanced and clear lens for evaluating AI tutoring systems for complex courses such as OR with high cognitive loads. The following

table summarized BCOR framework that can guide decision makers and instructors for successful instructional design and implementation of AI tutoring systems (Table 1).

Table 1. BCOR framework for adopting AI tutoring in math-based courses

Dimension	Description
Benefits	Immediate feedback Multimodal explanations Conceptual scaffolding to understand complex mathematical structures Access to individualized support beyond class time
Costs	Instructors' verifications of AI outputs Assignment redesigns Extra instructor effect to monitor misuse Cognitive overload if explanations are unclear or confusing Institutions costs for infrastructure, training, and equitable access
Opportunities	Personalized learning pathways Adaptive hinting Modeling-first guidance Support for "what-if" scenarios Visualize optimization structure Practice reasoning with complex constraints
Risks	Potential generation of incorrect steps Conceptual misconceptions Over-reliance on AI Weakening modeling intuition Equity gaps Academic integrity concerns

7. Conclusion

The rapid development of AI in education has created opportunities and capabilities for both students and instructors that AI tutoring is one of such applications. Using these tools help students to receive customized explanations and get a second eye to check their assignments and findings. At the same time, using such tools introduces critical challenges in achieving educational goals in classroom settings. This is even more vital in courses such as Operations Research that requires considerable amount of deep conceptual learning and multi-step calculations. This paper tried to highlight opportunities and challenges that using AI tutors can create for learning outcomes of such courses and discuss requirements that need to be included and considered in design of such systems. The discussion provided in this paper also highlights importance of implementing empirical studies on effectiveness and challenges created by AI assistance on learning math-based courses such as Operations Research. Evidence from real world experiments on undergraduate and graduate students in short term and long-term analysis can provide more clear maps on the advantages and disadvantages of such systems on achieving learning outcomes of such courses.

Acknowledgements

Portions of the text were refined with the assistance of an AI language model. The authors reviewed, edited, and take full responsibility for the content.

References

Abubakar, S., Jeilani, A., and Yusuf, M., "The role of over-reliance on AI in the negative consequences of student learning: The moderating effects of ethical concerns and institutional policies," *Cogent Education*, vol. 12, no. 1, p. 2591503, 2025.

Buçinca, Z., Malaya, M. B., and Gajos, K. Z., "To trust or to think: cognitive forcing functions can reduce overreliance on AI in AI-assisted decision-making," *Proceedings of the ACM on Human-Computer Interaction*, vol. 5, no. CSCW1, pp. 1-21, 2021.

Dhlamini, J. J., "Enhancing Learners' Problem Solving Performance in Mathematics: A Cognitive Load Perspective," *European Journal of STEM Education*, vol. 1, no. 1, pp. 27-36, 2016.

Favero, L., Pérez-Ortiz, J. A., Käser, T., and Oliver, N., "AI in Education Beyond Learning Outcomes: Cognition, Agency, Emotion, and Ethics," *arXiv preprint arXiv:2602.04598*, 2026.

Fisher, M., Goddu, M. K., and Keil, F. C., "Searching for explanations: How the Internet inflates estimates of internal knowledge," *Journal of Experimental Psychology: General*, vol. 144, no. 3, p. 674, 2015.

Goddard, K., Roudsari, A., and Wyatt, J. C., "Automation bias: a systematic review of frequency, effect mediators, and mitigators," *Journal of the American Medical Informatics Association*, vol. 19, no. 1, pp. 121-127, 2012.

Karamuk, E., "The automation trap: Unpacking the consequences of over-reliance on AI in education and its hidden costs," In *Pitfalls of AI integration in education: Skill obsolescence, misuse, and bias*, IGI Global Scientific Publishing, pp. 151-174, 2025.

Kulik, J. A., and Fletcher, J. D., "Effectiveness of intelligent tutoring systems: a meta-analytic review," *Review of Educational Research*, vol. 86, no. 1, pp. 42-78, 2016.

Lai, V., and Tan, C., "On human predictions with explanations and predictions of machine learning models: A case study on deception detection," *In Proceedings of the Conference on Fairness, Accountability, and Transparency*, pp. 29-38, 2019.

Leite, W. L., Zhang, H., Rana, S., Hao, Y., Hatch, A. D., Kong, L., and Kuang, H., "Do intelligent tutoring systems benefit K-12 students? A meta-analysis and evaluation of heterogeneity of treatment effects in the US," *arXiv preprint arXiv:2511.04997*, 2025.

Létourneau, A., Deslandes Martineau, M., Charland, P., Karran, J. A., Boasen, J., and Léger, P. M., "A systematic review of AI-driven intelligent tutoring systems (ITS) in K-12 education," *npj Science of Learning*, vol. 10, no. 1, p. 29, 2025.

Lin, C. C., Huang, A. Y., and Lu, O. H., "Artificial intelligence in intelligent tutoring systems toward sustainable education: a systematic review," *Smart Learning Environments*, vol. 10, no. 1, p. 41, 2023.

Ma, W., Adesope, O. O., Nesbit, J. C., and Liu, Q., "Intelligent tutoring systems and learning outcomes: A meta-analysis," *Journal of Educational Psychology*, vol. 106, no. 4, p. 901, 2014.

Sparrow, B., Liu, J., and Wegner, D. M., "Google effects on memory: Cognitive consequences of having information at our fingertips," *Science*, vol. 333, no. 6043, pp. 776-778, 2011.

Steenbergen-Hu, S., and Cooper, H., "A meta-analysis of the effectiveness of intelligent tutoring systems on college students' academic learning," *Journal of Educational Psychology*, vol. 106, no. 2, p. 331, 2014.