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A SEVEN-STAGE METHODOLOGY AND TASK BANK FOR TEACHING MATHEMATICAL MODELING OF AGROTECHNICAL PROBLEMS WITH AI-ASSISTED TOOLS

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ABSTRACT

This article presents a seven-stage methodology and an accompanying task bank, comprising 48 tasks (45 individual problems and three integration projects) organized into four thematic sections, for teaching mathematical modeling of agrotechnical engineering problems with AI-assisted tools. A five-criterion selection system - pedagogical effectiveness, professional context relevance, usability, financial-technical feasibility, and integration capability was applied to justify five core AI tools: Maple, Wolfram Alpha, GeoGebra AI, Python/Google Colab, and MATLAB/Simulink. The methodology's effectiveness was verified through a multi-site quasi-experimental study conducted across three higher education institutions (N=436) using Welch's t-test, ANCOVA, and MANOVA ($p<0.001$, $\eta^2=0.72$), while replication stability across sites was statistically confirmed (ICC=0.03).

Keywords: artificial intelligence, mathematical modeling, agrotechnical engineering education, task bank, AI tool selection criteria, engineering competence development.

1. INTRODUCTION

The rapid diffusion of artificial intelligence tools into engineering curricula has created a qualitatively new challenge for professional education: how to integrate these tools into the teaching of technically demanding, quantitative subject matter without displacing the independent analytical reasoning that engineering competence requires. Mathematical modeling of agrotechnical problems is a domain in which this tension is particularly acute, since future agricultural-mechanization engineers must learn to formulate, solve, and critically verify quantitative models rather than simply accept AI-generated output.

This article addresses that challenge by presenting a structured, seven-stage teaching methodology together with a task bank purpose-built for agrotechnical mathematical modeling, and by reporting the statistical evidence for the methodology's pedagogical effectiveness gathered from a multi-institutional quasi-experimental study.

2. LITERATURE REVIEW

Large-scale systematic reviews by Zawacki-Richter, Crompton, and Burke have documented the positive effect of AI integration on learning outcomes in higher education, while also cautioning that unsupervised use can weaken critical-thinking skills. Bastani and colleagues demonstrated that AI use without structured guardrails negatively affects learning outcomes, underscoring the need for consistent pedagogical oversight; conversely, Pardos and Bhandari showed that well-designed AI-generated pedagogical support can match the effectiveness of human tutoring. In the domain of statistical and computational methods for engineering problem-solving, foundational contributions by Box et al., Hyndman and Athanasopoulos, and Chow, Maidment, and Mays provide the methodological grounding for structured, staged approaches to teaching mathematical modeling.

3. METHODOLOGY

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Seven-stage teaching methodology. The proposed methodology structures the teaching of agrotechnical mathematical modeling into seven sequential stages, moving learners from problem formalization through model construction, computational implementation with AI-assisted tools, critical verification of AI-generated results, and reflective evaluation of the modeling process. Each stage is aligned with a corresponding assessment checkpoint, ensuring that reliance on AI tools is paired with demonstrable independent understanding.

Task bank structure. The accompanying task bank, adapted to the conditions of Uzbekistan's agrotechnical education, consists of four thematic sections and 48 tasks in total - 45 individual problems and three integration projects that require students to combine modeling techniques across multiple agrotechnical subdomains within a single AI-assisted workflow.

Five-criterion AI tool selection system. To ensure that AI tools are adopted on a principled rather than ad hoc basis, a five-criterion selection system was developed: pedagogical effectiveness, professional context relevance, usability, financial-technical feasibility, and integration capability. Applying these criteria to the agrotechnical education context identified five core tools - Maple, Wolfram Alpha, GeoGebra AI, Python/Google Colab, and MATLAB/Simulink - each selected for a distinct role within the seven-stage methodology (symbolic computation, interactive verification, and large-scale numerical simulation, respectively).

4. RESULTS

The pedagogical effectiveness of the methodology and task bank was evaluated through a multi-site quasi-experimental design across three higher education institutions - Termez State University of Engineering and Agrotechnologies, Samarkand Institute of Agroinnovations and Research, and Karshi State Technical University - involving a total of 436 second- and third-year students of the agricultural-mechanization education track. Statistical analysis, performed in IBM SPSS Statistics 26 and Python 3.11, confirmed the methodology's effectiveness at a high level of statistical confidence (Welch's t-test, ANCOVA, and MANOVA; $p<0.001$; $\eta^2=0.72$).

Cross-institutional stability of the results was confirmed by a low intraclass correlation coefficient (ICC=0.03), indicating that the observed effect was not driven by institution-specific factors and that the methodology generalizes across the three participating institutions.

5. DISCUSSION

The results indicate that a structured, staged approach to introducing AI tools into agrotechnical mathematical modeling instruction combined with an explicit tool-selection rationale and a purpose-built task bank can achieve statistically robust and institutionally stable learning gains. This is consistent with the broader literature's finding that the pedagogical value of AI in engineering education depends less on the tools themselves than on the structure within which they are deployed.

6. CONCLUSION

The seven-stage methodology and 48-task bank presented in this article provide a replicable, empirically validated framework for teaching mathematical modeling of agrotechnical problems with AI-assisted tools. The five-criterion tool-selection system offers a transferable procedure for other engineering education contexts seeking to adopt AI tools on a principled basis. Future work should examine long-term retention of modeling competence and extend the task bank to additional agrotechnical subdomains.

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