DIDACTIC POTENTIAL OF ARTIFICIAL INTELLIGENCE TECHNOLOGIES IN MATHEMATICAL MODELING

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Abstract: The rapid development of artificial intelligence (AI) technologies is creating new opportunities for improving the teaching and learning of mathematical modeling in higher education. Mathematical modeling requires students to transform real-world situations into mathematical representations, identify relevant variables, formulate assumptions, construct and solve models, interpret results, and evaluate the validity of obtained solutions. These stages require not only mathematical knowledge but also analytical thinking, creativity, critical reasoning, and decision-making skills.

Key words: artificial intelligence, mathematical modeling, mathematics education, generative AI, higher education, problem-solving.

Digital transformation has significantly changed contemporary higher education. Among recent technological developments, artificial intelligence has become particularly important because modern AI systems can process information, recognize patterns, generate explanations, produce computer code, analyze data, and support complex problem-solving activities. In mathematics education, AI technologies are increasingly considered not only as computational tools but also as potential learning partners, adaptive systems, teaching tools, and research instruments [1]. Mathematical modeling represents an especially important area for the educational application of AI. Unlike routine mathematical exercises in which students are usually given all necessary variables and formulas, modeling begins with a real-world situation. Students must determine which information is relevant, make assumptions, establish relationships among variables, select appropriate mathematical methods, solve the resulting model, and interpret the answer in relation to the original situation.

A simplified mathematical modeling cycle can be represented as follows:

Real-world problem → Problem analysis → Assumptions → Variables → Mathematical model → Mathematical solution → Interpretation → Validation → Revision

For example, suppose a university wants to estimate the number of buses required to transport 1,200 students to campus during the morning period. The problem does not initially provide a single mathematical formula. Students need to identify relevant variables such as bus capacity, average occupancy, number of trips, arrival time, travel duration, and possible variations in student demand.

If one bus has a capacity of 50 passengers, a very simple initial model may be written as:

N = S / C

where:

N = required number of bus trips,

S = number of students,

C = capacity of one bus.

Thus,

N = 1200 / 50 = 24.

However, the real situation is more complicated. Buses may not operate at 100% capacity, some students may use private transportation, and demand may vary during different periods. Mathematical modeling therefore requires the learner to evaluate assumptions and progressively refine the model. This is precisely where AI can have didactic value. AI can help students identify possible variables, formulate questions, compare alternative assumptions, generate scenarios, explain mathematical relationships, and evaluate model limitations. However, the educational objective should not be to allow AI to complete the modeling process instead of the learner.

Recent systematic research on ChatGPT in mathematics education has identified potential benefits such as immediate feedback, personalized assistance, step-by-step support, and opportunities for self-directed learning. At the same time, limitations involving complex mathematical reasoning, contextual understanding, and learner over-reliance have also been documented [2].

Consequently, the central pedagogical question is not simply "Can AI solve a mathematical problem?" Rather, it is:

"How can AI be integrated into mathematical modeling so that students develop stronger mathematical reasoning, modeling competence, and critical thinking?"

The purpose of this article is therefore to analyze the didactic opportunities of AI technologies in mathematical modeling and to identify pedagogically appropriate approaches to their integration into higher-education mathematics.

Artificial intelligence can be incorporated into different stages of mathematical modeling. Its role should vary depending on the learning objective. Recent research synthesizing systematic reviews of AI in mathematics education distinguishes several functional roles for AI, including adaptive infrastructure, learning partner, teaching tool, research tool, and learning content [1]. This distinction is particularly useful in mathematical modeling because modeling involves both structured mathematical procedures and open-ended reasoning. At the first stage, students must understand a real-world problem. AI can assist by helping learners identify potentially relevant and irrelevant information.

Consider the following problem:

"A farmer has 400 meters of fencing and wants to construct a rectangular field beside a river. No fence is required along the river. What dimensions maximize the area?"

Instead of immediately requesting the answer from AI, students can be instructed to ask:

"What variables should be considered in this problem? Do not solve it."

AI might suggest defining the width as **x** and the length as **y**.

Students then formulate the constraint:

$$2x + y = 400.$$

Therefore,

$$y = 400 - 2x.$$

The area is

$$A = xy,$$

so

$$A(x) = x(400 - 2x)$$

and consequently,

$$A(x) = 400x - 2x^2.$$

Students can then solve the optimization problem independently.

In this case, AI does not replace mathematical reasoning. Instead, it provides scaffolding at the stage where students translate a verbal situation into mathematical variables. This distinction is didactically important. If the learner simply enters *"Solve this problem"*, AI may remove the intellectual activity that the task was intended to develop. If the learner instead asks for hints, variables, alternative assumptions, or questions to consider, AI can function as a learning partner.

One of the most difficult stages of mathematical modeling is selecting an appropriate mathematical representation. Real situations rarely indicate whether a student should use a linear, quadratic, exponential, probabilistic, differential, or statistical model. Students must recognize relationships among quantities. For example, consider population growth.

Suppose the population of a small town is initially 50,000 and increases by approximately 3% each year.

Students may construct the exponential model

$$P(t) = P_0(1 + r)^t,$$

where:

$P_0 = 50{,}000$,

$r = 0.03$,

t = number of years.

Thus,

$$P(t) = 50{,}000(1.03)^t.$$

For ten years:

$P(10) = 50{,}000(1.03)^{10} \approx 67{,}196.$

AI can be used at the next stage to challenge the model rather than merely calculate the answer.

Students might ask:

"What assumptions does this exponential population model make?"

Possible issues include constant growth rate, migration patterns, economic changes, housing capacity, birth and death rates, and environmental limitations. This activity develops a fundamental modeling competence: understanding that mathematical models are simplified representations rather than exact copies of reality. AI therefore creates an opportunity to move beyond calculation toward discussion of the **validity and limitations of mathematical models**. Another important didactic opportunity is the ability to generate and compare different mathematical approaches. Traditional classroom tasks sometimes encourage students to search for one correct procedure. Mathematical modeling, however, frequently permits several valid models. Consider the problem of predicting future electricity consumption at a university.

Students might propose:

Linear model:

$E(t) = at + b$

or an exponential model:

$E(t) = E_0(1 + r)^t$.

A more advanced group might consider multiple regression:

$E = \beta_0 + \beta_1 S + \beta_2 T + \beta_3 H + \varepsilon$,

where:

S = number of students,

T = average temperature,

H = operating hours.

Students can ask an AI system to explain the advantages and disadvantages of these alternative models. Their task is then to decide which model is most appropriate and justify their decision mathematically.

Consequently, the didactic value of artificial intelligence in mathematical modeling does not depend primarily on how quickly AI can generate a solution. Its value lies in how effectively teachers use AI to stimulate questions, comparison, experimentation, verification, explanation, and reflection.

AI should therefore function as a **cognitive and didactic support tool**, while mathematical reasoning, decision-making, justification, and evaluation remain the responsibility of the learner.

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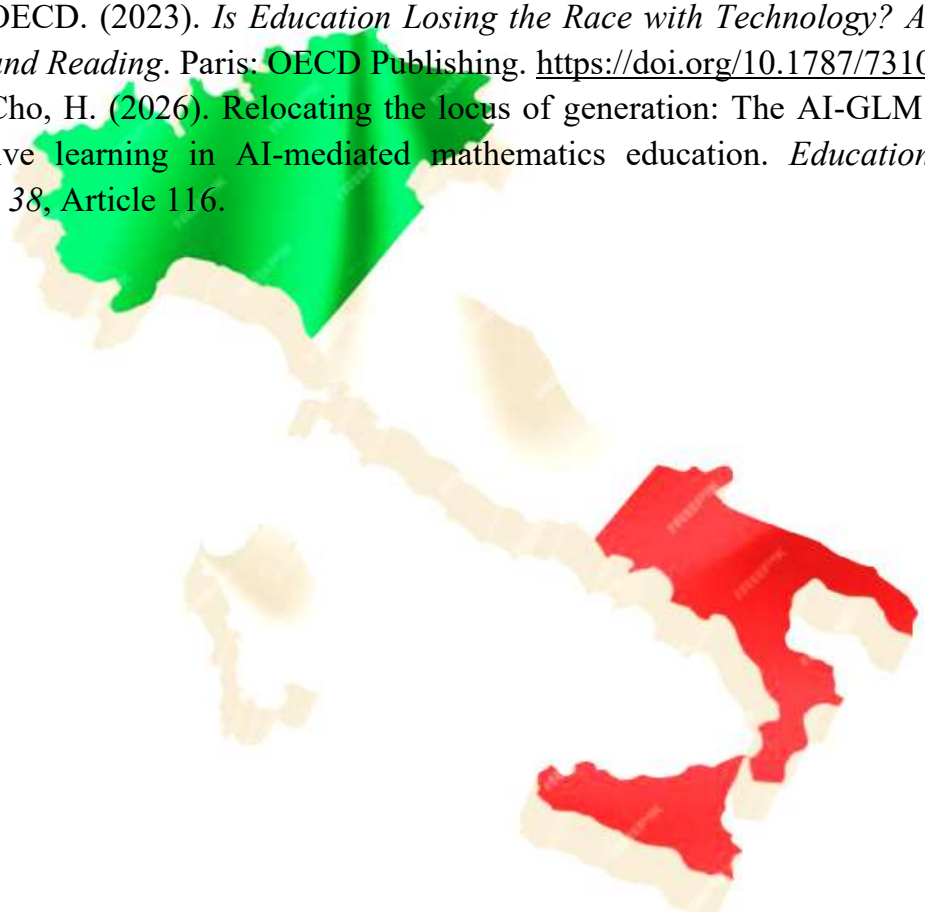
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