FROM CLASSROOM PRACTICE TO PEDAGOGICAL INNOVATION: AI-SUPPORTED MATHEMATICAL MODELLING FOR SUSTAINABLE FUTURES

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Mathematical modelling is widely regarded as a promising approach in mathematics education for exploring Sustainable Development Goals (SDGs). However, opportunities for mathematics teachers to design and teach modelling tasks are unevenly distributed. Generative artificial intelligence (GenAI) offers new possibilities to support such teaching activities. This study is a classroom-based exploratory research project. Starting with the design of mathematical modelling tasks on sustainable development themes, the researchers explored the potential of integrating AI into mathematical modelling instruction and cultivating students' sustainable development thinking by analyzing teacher-AI dialogue transcripts, mathematical modelling lesson plans, and classroom reflections.

INTRODUCTION

The initial idea for this study stemmed from a real-life teaching situation, where a teacher advocated for energy conservation and encouraged students to turn off the air conditioning when it was considered unnecessary, in order to reduce electricity consumption. The students raised questions about this initiative: *"How do we define 'unnecessary'?"* and *"To what extent does reducing air conditioner use, at the cost of some comfort, actually lead to lower carbon emissions?"* These questions highlight an important tension: although the concept of sustainable development is widely promoted in school education, students often lack opportunities to develop a quantitative understanding of how everyday environmental actions relate to their broader environmental impact.

In recent years, mathematics education research has increasingly engaged with pressing socio-ecological challenges, including climate change, energy consumption, and sustainable development (Makramalla et al., 2025). Scholars have argued that mathematics should not be treated as an isolated and abstract discipline and that mathematics education needs to be reconsidered in closer relation to the real world, enabling mathematical knowledge to serve as a tool for learners to make sense of complexity and uncertainty in contemporary contexts (Barwell et al., 2022). From this perspective, mathematics education is understood not only as the transmission of specific knowledge and skills but also as an educational practice that supports students in engaging analytically and critically with real-world problems.

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Mathematical modelling provides learners with the opportunity to explore complex phenomena using mathematics as a tool, and has been widely recognized as a way to connect mathematics education with sustainable development goals (Blum & Leiß, 2007; Stillman et al., 2013). Through modelling activities, students can hypothesize, quantify, analyze, and reflect on problems in real-world contexts, allowing relationships such as those between energy use, comfort, and carbon emissions to be explicitly expressed and discussed. Sustainability-oriented mathematical modelling tasks have been conceptualised as an important pedagogical approach for integrating disciplinary mathematical reasoning with broader social and environmental concerns (Wiegand & Borromeo Ferri, 2023).

Although the value of mathematical modelling instruction has been recognized, introducing mathematical modelling into many secondary school mathematics classrooms remains challenging. Previous research indicates that many teachers lack modelling experience and face difficulties in curriculum design and guiding students through open-ended modelling tasks (Blum, 2015). Limited teaching resources, time constraints, and the abstract and challenging nature of the curriculum hinder students' opportunities to participate in sustained modelling activities (Yang et al., 2025). Mathematical modelling is often considered an extracurricular enrichment activity for gifted students in schools with abundant educational resources, leading to unequal opportunities for students to learn mathematical modelling.

The latest developments in generative artificial intelligence (AI) offer possibilities for promoting mathematical modelling education and encouraging students to cultivate sustainable thinking. By referencing a large number of modelling examples, formulating modelling hypotheses based on specific contexts, and providing feedback during the problem-solving process, AI can assist teachers in designing modelling courses, guide students in applying mathematical knowledge to complete modelling tasks, and support students to approach problems with a sustainable mindset. Based on a semester-long teaching project, this study attempts to explore how artificial intelligence can participate as a teaching partner in modelling task design, teacher professional development, and student task guidance, aiming to answer the following questions: How did secondary school mathematics teachers use AI during the design and enactment of sustainability-oriented mathematical modelling tasks? How can AI-assisted mathematical modelling tasks promote student engagement in solving problems related to SDGs and cultivate their socio-ecological thinking?

METHODS

This study was designed as an exploratory qualitative classroom study conducted over one semester in a secondary school in Shanghai, China. The research focused on a mathematical modelling course that has been offered at the school since 2023. The course met twice a week and consisted of two parts: a foundational modelling lesson and a modelling problem inquiry lesson. It was open to students who were interested in mathematics and mathematical modelling and was closely connected to preparation

for mathematical modelling competitions. While some students initially joined the course with competition outcomes in mind, the broader instructional goal was to support sustained engagement in mathematical modelling and to help students develop a scientific and critical perspective on real-world issues related to SDGs.

The foundational modelling lessons were based on *A First Course in Mathematical modelling* (5th edition). As this textbook is primarily intended for undergraduate students, the teachers used AI tools as supportive assistants, together with their own teaching experience, to make pedagogical decisions and adjust the level of difficulty so that the content was more appropriate for high school learners. The modelling problem inquiry lessons drew on tasks selected from international mathematical modelling competitions, with a particular focus on themes related to sustainable development and socio-ecological issues. Teachers organized and categorized these tasks according to mathematical content, modelling complexity, and contextual emphasis. Students formed groups based on their interests and selected tasks from this structured task set. With guidance from teachers and support from AI tools, students read exemplary award-winning papers and, when necessary, reproduced existing code to better understand model structures and assumptions. This approach was intended to maintain a balance between student autonomy and instructional guidance. The use of artificial intelligence was optional and was explicitly framed as a supportive learning tool rather than an authoritative source of solutions.

Two experienced high school mathematics teachers participated in the study. Both had strong mathematical backgrounds, extensive teaching experience, and prior experience using AI in educational settings. Their involvement allowed the study to examine AI-supported modelling instruction from a teacher learning perspective, including lesson planning, instructional decisions, and classroom interactions.

At the beginning of the semester, 38 students (24 in year 10 and 14 in year 11) expressed interest and attended the initial sessions. As the course progressed, the number of active participants gradually decreased. Due to time constraints and the difficulty of the modelling course, by the end of the semester, 16 students (12 in year 10 and 4 in year 11) , working in four groups, completed the full modelling course and successfully participated in the 2025 High School Mathematical Contest in modelling. A comparison group of students with similar academic backgrounds (n=30) was also included. These students completed the same pre- and post-course questionnaires as the modelling participants as part of a subsequent mixed-methods research project. In this paper, the analysis focuses exclusively on qualitative classroom data in order to describe patterns in teachers' and students' experiences in the modelling course. All participants were informed about the purpose of the study, participation was voluntary, and pseudonyms were used to protect anonymity.

Open coding was conducted on classroom observation notes, interview transcripts, teacher reflections, and logs of teacher-AI interactions. The coding captured expressions related to engagement, uncertainty, confidence, frustration, and

collaboration. Self-Determination Theory (Ryan & Deci, 2000) was used as an interpretive lens to make sense of the emerging themes. Data related to teachers including interviews, reflections, and AI interaction logs and students including interviews, questionnaires, and classroom observations were analyzed separately in order to preserve the distinct perspectives of each group.

FINDINGS

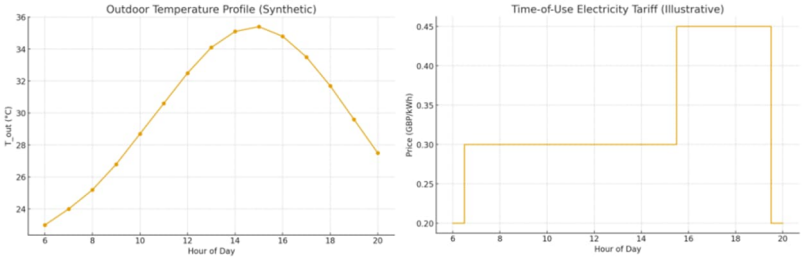
The research findings are organized around three themes, aiming to answer two research questions that focus on teachers' task design practices, students' engagement in complex modelling processes, and the development of socio-ecological reasoning abilities.

Teachers' design of sustainability-oriented modelling tasks with AI support

Teachers primarily described AI as a source of psychological and cognitive support during the lesson planning process. Rather than replacing teachers' professional judgment, AI functioned as a flexible support tool that teachers could selectively draw upon when encountering unfamiliar modelling content or open-ended task design challenges. The interviewed teachers reported using AI partially and strategically, rather than relying on it entirely. After completing a foundational modelling lesson, Teacher A reflected: *"I was very familiar with the differential equation content taught today, so I didn´ t rely much on AI. However, its presence gave me more confidence in designing the overall modelling course. Many of the models I learned at university have faded over time, and without additional instructional support, AI at least serves as a relatively reliable partner to discuss problems with."*

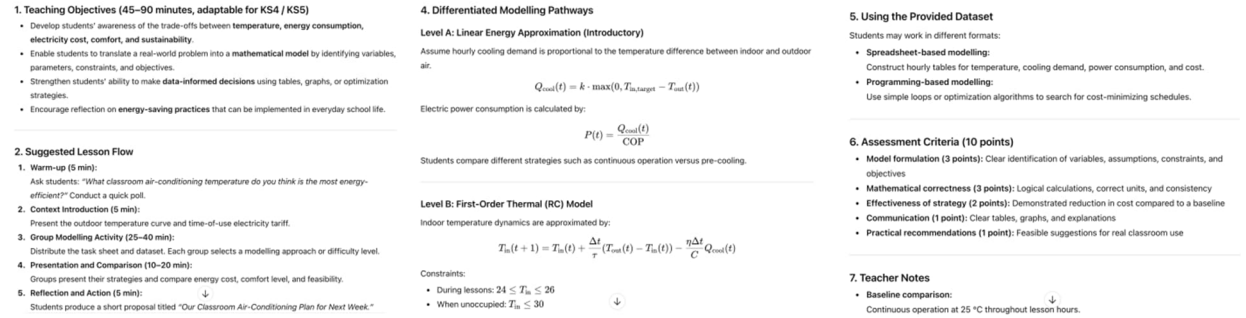
A recurring issue in teachers' accounts was the difficulty of designing mathematics modelling tasks oriented toward sustainable development without prior interdisciplinary teaching experience. Before engaging in AI-assisted planning, teachers needed to simultaneously consider students' existing knowledge while balancing mathematical structure, real-world context, and classroom feasibility within limited instructional time. Similar tensions have been reported by Helliwell and Ng (2022), who found that pre-service teachers viewed sustainability-related tasks as conceptually meaningful but practically difficult to implement. With AI support, teachers reported that the initial barriers to task design were reduced. AI-generated prompts, example datasets, and modelling frameworks enabled teachers to rapidly explore multiple task directions and evaluate their suitability for classroom use.

Fig.1: Simulated data generated by ChatGPT



Figures 1 and 2 illustrate excerpts from teacher - ChatGPT interactions concerning the "air-conditioning usage" modelling task. Starting from an initial prompt, the AI generated a relatively complete modelling task, including learning objectives, suggested lesson flow, task cards, tiered modelling pathways, guidance on using the provided data, assessment and evaluation criteria, and optional extensions. Notably, this entire process took approximately nine seconds. Teachers noted that AI-assisted tools allowed them to rapidly generate task drafts, datasets, or modelling narratives and adapt them for classroom use which is an outcome that would be difficult to achieve using traditional lesson planning approaches. This finding is consistent with previous research reported by Werth et al. (2024). As Teacher B humorously remarked during reflection: *"Nine seconds! If you gave AI the amount of time it usually takes me to write a modelling problem, it could probably produce over 800 of them."*

Fig.2: Partial content of the air-conditioning modelling task generated by ChatGPT



1. Teaching Objectives (45–90 minutes, adaptable for KS4 / KS5)

- Develop students' awareness of the trade-offs between **temperature, energy consumption, electricity cost, comfort, and sustainability**.
- Enable students to translate a real-world problem into a **mathematical model** by identifying variables, parameters, constraints, and objectives.
- Strengthen students' ability to make **data-informed decisions** using tables, graphs, or optimization strategies.
- Encourage reflection on **energy-saving practices** that can be implemented in everyday school life.

2. Suggested Lesson Flow

1. **Warm-up (5 min):**
   Ask students: *"What classroom air-conditioning temperature do you think is the most energy-efficient?"* Conduct a quick poll.
2. **Context Introduction (5 min):**
   Present the outdoor temperature curve and time-of-use electricity tariff.
3. **Group Modelling Activity (25–40 min):**
   Distribute the task sheet and dataset. Each group selects a modelling approach or difficulty level.
4. **Presentation and Comparison (10–20 min):**
   Groups present their strategies and compare energy cost, comfort level, and feasibility.
5. **Reflection and Action (5 min):**
   Students produce a short proposal titled *"Our Classroom Air-Conditioning Plan for Next Week."*

4. Differentiated Modelling Pathways

Level A: Linear Energy Approximation (Introductory)

Assume hourly cooling demand is proportional to the temperature difference between indoor and outdoor air.

$$Q_{\text{cool}}(t) = k \cdot \max(0, T_{\text{in,target}} - T_{\text{out}}(t))$$

Electric power consumption is calculated by:

$$P(t) = \frac{Q_{\text{cool}}(t)}{\text{COP}}$$

Students compare different strategies such as continuous operation versus pre-cooling.

Level B: First-Order Thermal (RC) Model

Indoor temperature dynamics are approximated by:

$$T_{\text{in}}(t+1) = T_{\text{in}}(t) + \frac{\Delta t}{\tau}(T_{\text{out}}(t) - T_{\text{in}}(t)) - \frac{\eta \Delta t}{C} Q_{\text{cool}}(t)$$

Constraints:

- During lessons: $24 \leq T_{\text{in}} \leq 26$
- When unoccupied: $T_{\text{in}} \leq 30$

5. Using the Provided Dataset

Students may work in different formats:

- **Spreadsheet-based modelling:**
  Construct hourly tables for temperature, cooling demand, power consumption, and cost.
- **Programming-based modelling:**
  Use simple loops or optimization algorithms to search for cost-minimizing schedules.

6. Assessment Criteria (10 points)

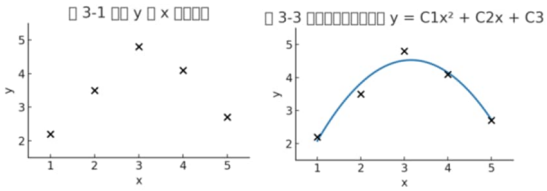
- **Model formulation (3 points):** Clear identification of variables, assumptions, constraints, and objectives
- **Mathematical correctness (3 points):** Logical calculations, correct units, and consistency
- **Effectiveness of strategy (2 points):** Demonstrated reduction in cost compared to a baseline
- **Communication (1 point):** Clear tables, graphs, and explanations
- **Practical recommendations (1 point):** Feasible suggestions for real classroom use

7. Teacher Notes

- **Baseline comparison:**
  Continuous operation at 25 °C throughout lesson hours.

Teacher-AI dialogues also revealed clear limitations of AI support. Figure 3 presents a case in which AI assistance did not fully meet the teacher's instructional expectations.

Fig.3: Image-based data generated by ChatGPT from a rough prompt



Teacher A initially intended to use a concrete mathematical example with explicit functions to illustrate the difference between polynomial interpolation and quadratic fitting. While the textbook provided data points and graphical representations of fitted curves, it did not specify the corresponding functions. Teacher A attempted to use AI to generate a specific quadratic equation consistent with the given graphical example. However, under an imprecise prompt, the AI failed to produce a function that was both graphically aligned and mathematically coherent. As a result, Teacher A ultimately retained the original textbook illustration and abandoned further formalisation. Reflecting on this experience, Teacher A noted: *"Maybe I didn't explain it clearly. If I kept refining the prompt, AI might eventually understand what I want, but by then I could have written it myself."*

Both participating teachers repeatedly emphasised in interviews that decisions about whether to adopt AI-generated content must rest on teachers' professional judgment. From their perspective, the success of AI support lies not in producing technically sophisticated outputs, but in efficiently generating materials that are genuinely usable in classroom instruction.

Students' access to complex modelling practices in an AI-supported environment

In the pre-course questionnaire, the term "coding" was mentioned with the highest frequency. Students' concerns were primarily centered on the perceived complexity of mathematical modelling knowledge and their unfamiliarity with programming skills. Several interviewed students expressed anxiety about their ability to complete modelling tasks. As one student noted: *"This course looks interesting, but it feels too difficult for me. I've never learned any programming before."* In this study, teachers introduced AI tools such as ChatGPT and Gemini into the classroom to support students in translating their modelling intentions into executable and interpretable code. This shift enabled high school students with limited programming backgrounds to move beyond purely theoretical discussions and actively engage in hypothesis testing, simulation, and basic sensitivity analysis. Students reported that they felt genuinely involved in the modelling process, rather than merely learning about modelling in an abstract or theoretical manner.

Fig.4: Students used Gemini to generate model code and obtained the results

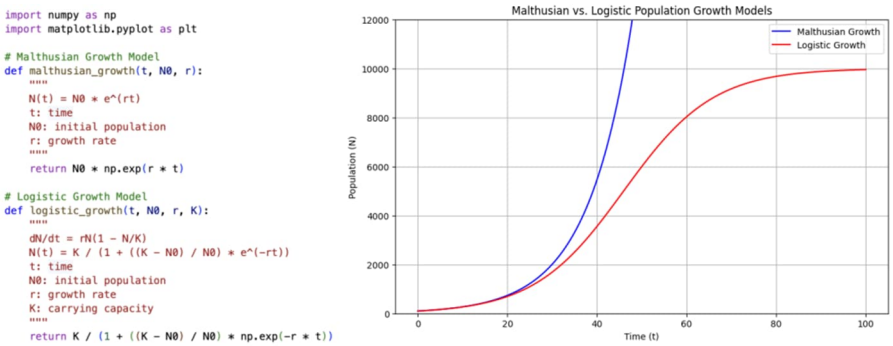


Figure 4 shows students comparing two population growth models based on an ecological game modelling context, using Gemini to generate Python code and obtaining the results. AI-assisted coding and interpretation created opportunities for iterative improvement. Students were encouraged in class to modify AI-generated code, adjust parameters, and interpret the output based on their modelling assumptions. These interactive teaching methods made students active decision-makers in the modelling process, allowing them to observe the consequences of their modelling choices through immediate feedback from simulations, enhancing their sense of efficacy and control over completing the task. Some students noted that even without programming experience, AI-assisted modelling allowed them to make meaningful contributions to group work, reducing feelings of exclusion and dependence on more technically proficient peers. From a self-determination theory perspective, AI-assisted

coding functioned as a competence-supportive resource, enabling students to participate meaningfully in modelling practices despite limited prior programming experience. Observations of classroom activities revealed that student engagement was lower (being distracted or sleeping in class) in relatively abstract lessons. Despite AI support, these activities were often perceived as disconnected from meaningful modelling purposes, thus limiting students' sense of efficacy. This contrast also suggests that AI-assisted competence support is context-dependent and related to the extent to which modelling tasks allow students to perceive the purpose and meaning of their actions.

From isolated tasks to thematic coherence in sustainability-oriented modelling

Taking the 2019 Mathematical Contest in modelling Problem A, *Ecological Game,* as an example, this problem required students to consider the breeding conditions of dragons and the environmental carrying capacity in a fictional scenario. Around this problem, the teacher introduced the logistic growth model to help students understand the patterns of population growth under limited resources. During the model construction and classroom reflection, students began to think of similar real-world ecological situations, such as the polar bear population conservation problem. In this process, AI did not provide students with new real-world examples, but rather served as a supportive tool, helping students quickly and repeatedly use and modify existing modelling structures. By continuously adjusting the parameters and assumptions in the model, students realized that, with appropriate conditions, mathematical models based on virtual assumptions can also be used to analyze and understand sustainable development problems in the real world.

Student questionnaire feedback provided an alternative perspective for understanding the classroom observation results. Students in the control group, when describing their views on environmentally friendly policies, tended to remain at a simple attitudinal level, such as "supporting less use of plastic" and "saving energy is good." In contrast, students participating in the mathematical modelling course were more inclined to discuss the realistic constraints, key assumptions, and optimal decision-making involved in policy implementation, starting from specific contexts and conditions.

This was particularly evident in the students' classroom analysis of Problem B, *Bottle Battles,* from the 2019 High School Mathematical Contest in modelling. Students constructed mathematical models around the seemingly clear environmental protection goal of the "plastic ban" policy, and in the process, gradually realized that the effectiveness of the policy was not a given, but highly dependent on specific contexts and parameter settings. Through modelling and analysis, students discovered that under certain conditions, the production and use of alternative packaging materials, changes in consumer behavior, and infrastructure limitations resulting from the "plastic ban" policy could lead to increased, rather than decreased, environmental costs. It was through this model-based empirical analysis that students began to understand that mathematical modelling can not only support environmental stances but also reveal

counterintuitive or even negative impacts of policies in specific situations. In the questionnaire survey, students did not easily choose "good" or "bad" for environmental policies, and in subsequent interviews, they were able to present their own views and hypotheses. Their understanding of sustainable development issues gradually shifted from value judgments to structured reasoning based on conditions, constraints, and empirical analysis.

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