# Learning with and About Artificial Intelligence in the Introductory Chemistry Course

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**Abstract**

*Chemical propaedeutic courses serve as a central bridging function between school-level chemistry education and the disciplinary, methodological, and epistemic demands of university-level chemistry study. From a chemical education research perspective, the focus is not merely on aligning prior knowledge, but on fostering robust foundational concepts, developing appropriate representational competencies, and deepening understanding of chemical modes of thinking and working. At the same time, generative AI systems are increasingly shaping the learning practices of first-year students - often in an unguided manner and without explicit didactic framing.*
*In response to these developments, this contribution proposes a chemistry education - based framework for integrating AI elements into an introductory course. AI is not conceived merely as a tool for efficiency, but as a stimulus for disciplinary learning, conceptual clarification, and metacognitive reflection. Key elements include task designs grounded in fundamental chemical concepts, the structured use of AI-supported learning activities across different competence levels, and the systematic development of critical AI literacy.*
*The framework explicitly addresses characteristic constraints of chemical propaedeutic courses, including limited instructional time, high content density, heterogeneous student populations, and diverse prior experiences with chemical models and quantitative procedures. Its applicability is illustrated through exemplary task formats derived from chemistry education research.*

**Keywords:** *Artificial intelligence, Chemistry preparatory course, AI literacy, AI-supported learning methods*

## 1. Introduction

From a chemistry education research perspective, chemical propaedeutic courses fulfil a dual function. On the one hand, they aim to address heterogeneous disciplinary entry conditions; on the other, they make central modes of chemical reasoning and practice explicit and support their consolidation. First-year students need to learn to navigate between different levels of chemical representation (macroscopic, submicroscopic, and symbolic), to work with models, to conceptualize chemical quantities relationally, and to apply mathematical competencies. These demands clearly extend beyond the mere repetition of secondary school content.
At Georg August University of Göttingen, the *Chemtroduction* programme has fulfilled this bridging function since 2014. [1] It addresses typical transition-related difficulties, such as uncertainties in working with amount of substance, stoichiometric relationships, and the disciplinary precision of chemical terminology. At the same time, research indicates that many of these difficulties are attributable less to deficits in factual knowledge than to insufficiently consolidated foundational concepts and representational competencies. [2,3]
Parallel to these established challenges, the learning environment has changed fundamentally in recent years. Generative AI systems are readily available to students and are already being used at the beginning of their studies - for example, to generate explanations, solve mathematical problems, or rephrase technical content. [4,5] Such use often remains implicit and is not accompanied by explicit engagement with the question of whether AI-generated outputs are disciplinarily valid, model-appropriate, or conceptually viable. [6-8]
In context of chemical propaedeutic courses, this creates a particular tension. On the one hand, AI systems can provide individualized explanations and support learning processes. On the other hand, there is a risk that incorrect or oversimplified AI-generated responses may reinforce existing misconceptions, especially when students do not yet possess sufficiently consolidated disciplinary and model-based competencies.

***Specific Challenges of a Preparatory Course in Chemistry***

The integration of AI into a chemical propaedeutic course must take these discipline-specific and learning-process - related characteristics into account. Typical contextual conditions include:

- **Limited time:** Core chemical concepts must be established and consolidated within a short period; any additional AI elements therefore need to be integrated in a clearly functional manner.
- **Heterogeneous student groups:** Differences in prior knowledge affect not only content aspects, but also changes in representation, mathematical routines, and model understanding.
- **High conceptual density**: Many topics (e.g., amount of substance, chemical equations, bonding models) are conceptually demanding and highly interrelated.
- **Methodological demands**: Chemical problem solving requires the interaction of qualitative models, quantitative relations, and symbolic representations.

These conditions illustrate that AI cannot be integrated merely as an additive component. What is required is a coherent, chemistry education - based framework that purposefully embeds AI in the development of disciplinary and model-based understanding. This paper aims to conceptually design a chemical propaedeutic course so that students

- understand and apply foundational chemical concepts,
- systematically develop representational and model-based competencies,
- use AI reflectively as a learning support tool,
- develop a disciplinary, critically informed AI literacy.

**2. Concept for AI Implementation in the Preparatory Course**

The integration of AI is primarily based on didactic rather than technological considerations. Three guiding principles structure the concept and serve as a framework for task design, teaching organization, and assessment.

***Constructive Alignment***

The starting point is the principle of constructive alignment. [9] Learning objectives, learning activities, and assessment formats are systematically aligned. The use of AI is an explicit component of the instructional design and is not left to students' individual discretion.
Depending on the targeted competence level, AI may be explicitly permitted, restricted, or excluded. In early practice phases, AI-supported tools are provided to enable individualized feedback and to accommodate heterogeneous prior knowledge. In other phases – such as the assessment of basic calculation skills or conceptual understanding – the use of AI is deliberately restricted to make independent competencies visible. Exam formats can either require AI-free work or make the competent use of AI itself the subject of assessment. [5,6,10]

***Transparency and Clarity of Rules***

A second guiding principle is consistent transparency. For all task formats, it is clearly communicated whether and in what form AI may be used. A tiered labeling system has proven effective for learning (e.g., 'AI prohibited', 'AI permitted', 'AI required').

This clarity reduces students' uncertainties and supports the acceptance of the guidelines. At the same time, the didactic rationale for each AI application is made explicit, allowing students to understand why AI is appropriate in certain contexts and deliberately restricted in others.

***Promoting Critical AI Literacy***

The concept explicitly aims to develop critical AI literacy. [6-8,10] AI is not only used as a supportive tool but also becomes an object of study itself. Students learn to evaluate AI-generated outputs for disciplinary accuracy, identify common sources of error, and classify results appropriately.
This critical perspective is closely linked to disciplinary learning. The analysis of incorrect or oversimplified AI responses not only fosters digital literacy but also deepens students' understanding of chemical concepts, reasoning structures, and scientific rigor.

**3. Implementation of AI components in the Preparatory Course**

The concept is implemented using three didactic AI modules, each emphasizing a distinct role of artificial intelligence in the subject-specific learning process:

I. Learning, practicing, and applying
II. Deepening and connecting concepts
III. Reflecting, producing, and problem solving.

The use of AI is consistently framed by didactic considerations and is designed to stimulate, structure, and support disciplinary learning processes reflectively, without replacing them.

***AI-Supported Practice Tasks: AI as a Learning-Support Tool***

In AI-supported practice tasks, artificial intelligence is deliberately employed as a learning-support tool that can accompany, comment on, and make individual problem-solving processes accessible for reflection. The aim is to build or consolidate disciplinary routines, deepen conceptual understanding, and enable students to justify and critically evaluate their own solutions. AI does not primarily act as an automatic problem solver; rather, it functions as a structured stimulus for learning. [10] A central task format, for example, could be a 'stoichiometry assistant'. Students first solve stoichiometric problems independently and then use AI to review their approaches, explore alternative solutions, and identify potential sources of error. The use of AI follows clearly framed prompt guidelines, which aim not merely to generate complete model solutions. Instead, the AI provides commentary on intermediate steps, poses guiding questions, and highlights potentially conceptually relevant pitfalls. An essential didactic element of this format is the deliberate confrontation with incorrect or incomplete AI outputs. Figure 1 exemplarily shows such a task within the introductory course.

**Fig. 1:** Example task of the introductory course to 'Stoichiometry and Chemical Equation' as learning-support tool.

***AI-Supported Conceptualization: Analyzing and Structuring Disciplinary Relationships***

In addition to computational and symbolic practice tasks, AI-supported exercises can be used to

**Example Task (Stoichiometry and Chemical Equations)**

Gaseous ammonia reacts with gaseous hydrochloric acid to form a crystalline solid.

1. First, independently formulate the balanced chemical equation, including correct stoichiometric coefficients and physical states (AI prohibited).
2. Subsequently use AI to generate the same reaction in two variants (AI required):
   a. chemically correct,
   b. intentionally incorrect (e.g., incorrect physical states, inconsistent stoichiometry, or unjustified simplifications). The AI should make its reasoning and steps transparent.
3. Systematically compare all three representations and justify your evaluation with reference to chemical concepts (AI permitted).

conceptually structure chemical content. In this context, AI serves as a generator of preliminary organizational proposals, which are then evaluated, refined, and further developed by students. The goal is to foster an integrated understanding of the discipline and to encourage deliberate engagement with models, conceptual relationships, and varying levels of explanatory depth. Typical applications include concept maps, model overviews, or explanatory text structures that relate central chemical concepts. Students analyze the AI outputs with respect to disciplinary accuracy, completeness, and model consistency. This task format can help foster the ability to critically reflect on chemical models, not only in terms of reproducing them but also regarding their scope, limitations, and explanatory power.

**Example Task (Bonding Models and Material Properties)**

Bonding models serve as a central tool for structuring chemical knowledge.

1. First, independently create a summary from memory comparing covalent, ionic, and metallic bonding (AI prohibited).
2. Then, have the AI generate a concept map or tabular overview addressing the same bonding types (AI required).
3. Systematically analyze both the AI-generated output and your own summary: (AI permitted):
   a. Which conceptual relationships are represented correctly?
   b. Where are models oversimplified, conflated, or inappropriately generalized?
   c. Which material properties (e.g., melting pint, electrical conductivity) are explained accurately or insufficiently?
4. Compare your summary and the AI output with scientifically accepted references (e.g., textbook, recommended scholarly sources) (AI prohibited).
   a. Which statements are scientifically correct and complete?
   b. Which statement are simplified, model-dependent, or context-specific?
   c. Are there statements that require further refinement or qualification?

**Fig. 2**: Example task of the introductory course to 'Bonding Models and Material Properties' for deepening and connecting concepts.

***Productive and Reflective Extension: Task Assessment and Task Creation with AI***

Building on earlier phases of practice and conceptualization, students progressively assume a more productive and reflective role. In this module, AI systems are used to generate students' own chemistry-related practice tasks or explanatory representations, which are subsequently subjected to disciplinary and didactic evaluation and iterative revision. The focus is placed less on the mere generation of tasks and more on the critical examination of their quality. Through this process, students come to recognize that AI-generated outputs which appear plausible or formally correct are not necessarily scientifically accurate or pedagogically meaningful. This task format aims to foster the development of students' disciplinary judgement and didactic understanding of chemical learning processes, thereby enabling them to critically identify the limitations of AI-generated educational content.

**Example Task (Task Quality and Didactic Alignment)**

The concept of amount of substance is associated with widespread misconceptions in chemistry learning.

1. First, independently formulate a practice task on the concept of amount of substance (*n*) at the university level that goes beyond mere formula application and requires conceptual understanding (AI prohibited).
2. Subsequently use AI to generate two additional practice tasks targeting the same learning objective (AI required).
3. Evaluate all three tasks with respect to (AI prohibited):
   a. scientific accuracy,
   b. conceptual depth.
4. Revise one of the AI-generated tasks in a targeted manner to improve its scientific precision and didactic coherence, and justify the modifications made (AI prohibited).
5. Present the self-developed task as well as the AI-generated and revised tasks in the seminar. Jointly discuss the extent to which the tasks contributed to participants' understanding of the concept of amount of substance (AI prohibited).
6. Conclude with a reflection on the points at which AI supported understanding and where new questions or uncertainties emerged (AI prohibited).

**Fig. 3:** Example task of the introductory course to 'Task Quality and Didactic Alignment' for training a critical evaluation.

## 4. Outlook

The presented concept is intended as a structured proposal for integrating AI into an introductory chemistry course. It illustrates that, within a clearly defined didactic framework, AI can simultaneously support the development of disciplinary knowledge and foster critical media literacy, enabling students to evaluate the reliability and relevance of AI-generated content.
For the winter semester 2026/27, a systematic evaluation of the AI integration is planned. This study will investigate its impact on disciplinary learning outcomes, student strategies for AI use, attitudes toward AI in scientific contexts, and perceived cognitive load or alleviation. The findings are expected to guide iterative refinement of the instructional design and to provide evidence for its transferability to other STEM introductory courses.
A central principle of the approach is that AI is not a substitute for disciplinary learning. Rather, it is framed as a controlled, pedagogical tool that scaffolds students’ conceptual understanding, problem-solving skills, and methodological competencies in chemistry.

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