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A Methodological Framework for Contextual and Adaptive Instruction of Higher Mathematics in Chemistry Education

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Abstract. *This article explores a system for teaching higher mathematics to students majoring in chemistry, using adaptive and integrative approaches. Within the proposed framework, mathematical topics are introduced in a chemical context, tailored to individual learning needs, and presented through real-life examples. The article describes the main instructional stages, key principles, and pedagogical benefits of the system. The approach enhances interdisciplinary thinking, fosters independent reasoning, and strengthens students' professional preparedness*.

Keywords: *higher mathematics, chemistry, adaptive learning, integration, interdisciplinary education, contextual teaching.*

Introduction

There is a growing need to align the content of higher mathematics courses for chemistry students with their professional context and to adapt the instructional process to individual learner characteristics. Traditionally, mathematics is taught as a separate, abstract discipline, which often creates difficulties for chemistry students and hinders their ability to apply mathematical concepts in practice [1]. The proposed methodological framework is built upon two core principles: adaptivity—adjusting instruction to students' preparedness and needs—and integration—embedding mathematical concepts within a chemical context.

In this system, every topic in higher mathematics is taught through real examples derived from chemistry. The theoretical material is linked to relevant chemical processes, formulas, or data. This connection not only demonstrates the practical application of mathematical knowledge but also boosts students' motivation [4]. According to the theory of contextual learning, connecting theoretical concepts to real-life situations supports deeper and more conscious understanding [5]. The adaptive approach ensures personalized learning trajectories based on individual learning capacities and cognitive styles [2].

The following sections describe the structure of the lessons, participants' roles, pedagogical stages, and the scientific underpinnings of the proposed system.

Teaching Process Stages

In the adaptive-integrative framework, each lesson is organized into several clearly defined stages. Each stage has a specific purpose and content, arranged sequentially to ensure an effective learning experience for students. The key stages are as follows:

1. Introduction Stage (Motivation and Context Creation)

At this stage, the instructor introduces the new topic and links it to a chemical context. A real problem or process in chemistry is presented to capture students' attention. For example, when covering the topic of 'Extrema', the instructor might describe a scenario involving the maximum rate of a chemical reaction or the influence of temperature on a substance. The instructor also activates students' prior knowledge and may use diagnostic questions to assess readiness. This phase addresses the question: 'Why are we learning this?'

Teacher: Announces the lesson topic and goal, connects it with a real-world chemical situation to motivate students, and poses questions to activate prior knowledge. Observes students' responses to adapt the lesson difficulty accordingly (adaptive approach).

Student: Focuses on the given chemical situation, attempts to answer questions based on prior experience, and begins to see the relevance and importance of the topic.

2. Theoretical Explanation Stage

Following the motivational setup, the instructor presents the mathematical theory behind the topic. Key definitions and formulas are introduced in a simple and clear way, immediately linked to chemical applications. For instance, while explaining differential equations, their relevance to reaction kinetics is illustrated. Visual aids like graphs or diagrams may be used to enhance understanding.

Teacher: Explains theory clearly, contextualizes every formula with chemical meaning, and adjusts explanations when difficulties arise. Follows a modular structure, checking comprehension after each block with brief Q&A.

Student: Listens attentively, takes notes, connects mathematical concepts with chemistry knowledge, and actively participates in Q&A sessions to clarify doubts.

3. Integrated Example Stage (Practical Application)

Once theory is covered, instructor and students collaboratively solve a contextual problem. This example connects theoretical learning with practical use. For example, while learning about integrals, students might model the change in concentration of a chemical over time and calculate the total amount used. Or, during logarithms, they might linearize the Arrhenius equation using log operations.

Teacher: Analyzes the problem step-by-step, provides guiding questions, adjusts difficulty based on student responses, and highlights the chemical meaning of each step.

Student: Solves the problem by applying theoretical knowledge in a chemistry context, collaborating with peers if applicable, and demonstrates problem-solving competence.

4. Consolidation Stage (Independent Practice)

Students then solve additional problems independently or in small groups to consolidate their understanding. The complexity and number of tasks are adjusted adaptively—basic tasks for those needing reinforcement, and advanced challenges for high achievers. All tasks remain within the chemistry context to ensure relevance.

Teacher: Distributes exercises, monitors progress, and offers personalized feedback. Supports struggling students and challenges advanced ones.

Student: Completes tasks independently, applies learned formulas, asks for help when needed, and reflects on mistakes to reinforce knowledge.

5. Conclusion Stage (Reflection and Assessment)

The final stage involves summarizing the topic and encouraging student reflection. The teacher recaps key formulas and conclusions, and asks questions like 'What did we learn? How can it be applied?' Reflection helps students evaluate their own learning, recognize strengths and weaknesses, and connect knowledge to future applications.

Teacher: Facilitates discussion, encourages feedback, praises effective participation, and conducts rapid assessment through Q&A, quizzes, or solution reviews.

Student: Reflects on the learning process, articulates key takeaways, identifies unclear points, and prepares mentally for future topics based on feedback received.

Core Pedagogical Principles of the Methodological Framework

The proposed system is grounded in several modern pedagogical principles that support its successful implementation:

1. Contextual Approach

This principle involves delivering educational content within the context of the students' future professional activities. Based on Verbitsky's theory, it bridges the gap between theory and practice and enhances students' perception of relevance. In this system, every mathematical topic is connected to real-life chemical problems. As a result, students perceive knowledge not in isolation, but in terms of practical application, which improves knowledge retention and transferability.

2. Interdisciplinary Integration

This principle focuses on connecting mathematics with chemistry, ensuring cross-disciplinary coherence. Research shows that integrated teaching methods significantly enhance the efficiency of the learning process [3]. In this system, students apply chemistry knowledge during math lessons and vice versa, fostering the development of combined competencies such as analytical and scientific reasoning.

3. Adaptive (Learner-Centered) Approach

This principle recognizes that each student has a unique level of knowledge, interests, and learning pace. Adaptive learning technologies are an effective means in modern education for personalizing instruction [2]. In this methodology, instructors adjust task difficulty and lesson structure to meet students' needs. High-performing students receive advanced problems, while those requiring support receive simplified guidance. Course content is modular and adaptable to focus on the most relevant math topics for chemistry majors.

4. Constructivist Principle

According to the Constructivist Learning Theory, students actively construct knowledge through engagement and inquiry rather than passive reception. This system promotes constructivism through interactive, problem-based learning—students solve examples, engage in discussions, and discover new knowledge independently, with the teacher acting as a facilitator. This enhances critical thinking and problem-solving skills.

5. Modularity and Systematic Structure

Course content is organized into self-contained modules, each integrating chemistry and mathematics. For instance, a module might focus on differential equations used in chemical kinetics. All modules follow a logical sequence and collectively form the complete curriculum. Modularity allows flexible planning and gradual introduction of integrated content, while systematic organization ensures internal coherence and consistent learning outcomes.

6. Reflective Practice

This principle emphasizes student reflection on their own learning. At the end of each lesson and module, students consider what they have learned, why it matters, and how they can apply it in the future. This process develops metacognitive skills and encourages intentional learning. Reflection also allows instructors to monitor student progress and refine teaching strategies accordingly [7].

The combination of these principles underscores the scientific and methodological robustness of the system. It integrates both content innovation and pedagogical advancement, aiming to transform mathematics education for chemistry students

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