



# The Role of Analytical Chemistry in the Formation of Professional Competencies of Future Chemistry Teachers

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## ABSTRACT

The article examines the role of the Analytical Chemistry course in the formation of professional competencies of future chemistry teachers within a competence-based education framework. Cognitive, activity-based, and motivational components of teacher preparation are analyzed as key elements of professional readiness. Special attention is given to the methodological significance of analytical chemistry, particularly the teaching of analytical methods as a foundation for scientific thinking, research skills, and evidence-based reasoning. To strengthen the conceptual discussion, a case-based empirical approach is incorporated, demonstrating how analytical chemistry instruction supports competency development through real-world environmental analysis tasks. The integrative potential of analytical chemistry in environmental, biological, and educational contexts is highlighted. Analytical chemistry is presented not only as a specialized scientific discipline but also as a universal educational tool that ensures the systematic development of professional competencies and promotes environmental awareness among future teachers.

**Keywords:** analytical chemistry; chemistry education methodology; professional competencies; scientific thinking; interdisciplinary integration; environmental education; chemistry teacher training

## INTRODUCTION

Global transformations in education systems have significantly reshaped learning objectives, content, and value orientations, resulting in new requirements for the professional preparation of future chemistry teachers. Modern education demands teachers who possess strong subject knowledge alongside well-developed analytical, research, and interdisciplinary thinking skills.

Recent studies emphasize that contemporary science education should be oriented toward competency development, inquiry-based learning, and sustainability (OECD, 2020; UNESCO, 2021; Seery, 2020).

Analytical Chemistry plays a central role in this process, contributing to observation, data collection, critical analysis, and evidence-based reasoning (Harris, 2016; Skoog et al., 2014).

### Methodological Role of Analytical Chemistry in the Professional Preparation of Future Chemistry Teachers

Analytical chemistry plays a fundamental role in the methodological development of chemical science and education. Its teaching extends beyond the identification and quantitative determination of substances; it serves as a powerful tool for fostering scientific thinking and inquiry-based learning.

Through the study of analytical methods, students develop the ability to formulate research questions, select appropriate methodologies, design experiments, and critically interpret results. These skills are essential for evidence-based reasoning and reflect the core principles of modern science education (Towns, 2020; Hofstein & Kind, 2022).

In the context of teacher education, this methodological approach is particularly significant. Analytical chemistry functions not only as a disciplinary field but also as a universal educational model that integrates theoretical knowledge with practical application. It supports the development of transferable competencies, including problem-solving, data analysis, and reflective thinking.

Moreover, aligning with contemporary educational frameworks, analytical chemistry contributes to competency-based and sustainability-oriented learning by engaging students in real-world contexts and interdisciplinary problem-solving (OECD, 2020; UNESCO, 2021).

### **Analytical Chemistry and the Development of Professional Competencies**

The integrated use of analytical chemistry in the educational process contributes to the formation of the following professional competencies in future chemistry teachers:

#### **Cognitive competence**

Cognitive competence involves understanding principles of chemical reactions, analytical signals, and quantitative determination methods. The Analytical Chemistry course deepens students' subject knowledge and enables them to analyze chemical processes at both microscopic and macroscopic levels. Classical and modern analytical methods, such as titrimetry, photometry, and spectroscopy, facilitate understanding reaction conditions and evaluating the reliability of analytical results (Harris, 2016).

**Example:** Determining the ionic composition of water samples allows students to interpret analyze analytical signals (color changes, precipitate formation, optical density changes) and relate them to reaction mechanisms. This promotes causal reasoning rather than rote memorization.

#### **Activity-based competence**

Laboratory work is a central component of analytical chemistry education, bringing students closer to real research practice. Instructional experiments are designed to encourage students to independently define research objectives, select appropriate analytical methods, and process experimental data.

**Example:** Water quality analysis (including pH, total hardness, calcium and magnesium ions, chlorides, sulfates, and nitrogen-containing compounds) integrates multiple competencies:

- Stoichiometric calculations
- Logical selection of analytical methods
- Statistical data processing
- Environmental interpretation of results

Students compare their results with established regulatory standards, which enhances the practical relevance of chemical analysis and strengthens their ability to apply knowledge in real-world contexts.

#### **Motivational Competence**

Motivational competence is reflected in students' engagement, creativity, and sense of responsibility. Participation in research-oriented activities encourages independent decision-making and problem-solving.

- Students make independent decisions during research activities.
- They solve practical problems, such as assessing water pollution or analyzing agricultural runoff.
- They develop environmental awareness and recognize chemistry's role in environmental protection and human health (Holme & Murphy, 2012).

**Example:** Students work collaboratively to analyze environmental samples, compare their findings with regulatory requirements, and present their conclusions. This process fosters communication skills, teamwork,

and environmental awareness, while highlighting the role of chemistry in environmental protection and public health.

### Empirical Illustration: Case-Based Learning Approach

A case-based empirical approach was integrated into the course through environmental water analysis.

### Research Design

Students performed:

- Sample collection
- Method selection
- Laboratory analysis
- Data interpretation

International standards (ISO, EPA) were applied.

### Analytical Methods

- Major ions
- pH (potentiometric)
- Total hardness (complexometric)
- Nitrogen compounds
- Trace elements

### Assessment Framework

The competency development was evaluated using a structured rubric-based model (Table 1).

**Table 1. Competency-Based Assessment Framework**

Competency Type	Indicators	Assessment Methods	Expected Outcomes
Cognitive	Understanding analytical principles; explaining processes	Tests; oral assessment	Accurate interpretation
Activity-based	Laboratory skills; data analysis	Lab reports; practical tasks	Experimental competence
Motivational	Engagement; responsibility	Observation; projects	Increased motivation

### Educational Outcomes

Students demonstrated:

- Improved application of knowledge
- Development of analytical thinking
- Enhanced problem-solving skills
  
- Increased motivation

### Iner disciplinary Integration

Analytical chemistry is effectively integrated with other disciplines:

- **Biology:** Analysis of microorganisms in aquatic ecosystems, effects of toxic substances on biological processes.

- **Environmental Science:** Analysis of wastewater, monitoring air and soil pollution.
- **Educational Practice:** Data analysis, research-based projects, development of environmental awareness among school students (Bybee, 2013).

**Example:** Students develop small-scale school projects involving water analysis, investigate chemical composition, and prepare recommendations to strengthen environmental responsibility.

### Methodological Implications of Analytical Chemistry in Teacher Education

The methodological dimension of analytical chemistry plays a key role in fostering scientific thinking and professional competence in future chemistry teachers. It emphasizes the development of essential research skills, including the correct formulation of research problems, the selection of appropriate analytical methods, and the evaluation of the accuracy and reliability of results.

Students are trained to interpret chemical phenomena within broader biological, environmental, and social contexts, which enhances their ability to apply knowledge in interdisciplinary settings. This approach supports the transition from theoretical understanding to evidence-based reasoning and decision-making.

**Example:** A pre-service chemistry teacher applying spectrophotometric analysis compares samples from different sources and formulates evidence-based conclusions using defined evaluation criteria. Such activities strengthen analytical thinking, methodological awareness, and scientific responsibility.

Interdisciplinary integration is particularly important in environmental contexts, where students learn to analyze chemical processes as part of complex ecological systems and to engage in environmental monitoring and assessment.

From a pedagogical perspective, the findings highlight several key methodological implications:

- Inquiry-based learning
- Laboratory-centered instruction
- Integration of real-world applications
- Competency-based assessment

These elements align with contemporary approaches to science education and support the development of transferable professional competencies.

## CONCLUSION

The theoretical analysis presented in this article demonstrates that analytical chemistry occupies a key position in the professional preparation of future chemistry teachers, functioning not only as a specialized scientific discipline but also as a powerful methodological and educational foundation. Within a competence-based educational framework, analytical chemistry effectively supports the systematic formation of cognitive, activity-based, and motivational competencies that are essential for modern chemistry teaching.

The study shows that teaching analytical methods contributes significantly to the development of scientific thinking, critical analysis, and research skills. The ability to formulate research problems, select appropriate analytical techniques, evaluate the accuracy and reliability of experimental results, and interpret data in a meaningful way enhances both subject mastery and pedagogical effectiveness. These competencies are crucial for implementing contemporary, inquiry-based approaches in school chemistry education.

Furthermore, the high integrative potential of analytical chemistry with environmental, biological, and educational disciplines is highlighted as a major advantage of this course in teacher education. Interdisciplinary learning contexts, particularly those related to environmental analysis and monitoring, enable future teachers to connect chemical knowledge with real-world problems and to foster environmental awareness and responsibility.

among school students. This approach is especially relevant in the context of current global environmental challenges.

From a practical perspective, the conclusions of this study may be applied to the revision and improvement of chemistry teacher education programs, particularly in designing the content and teaching strategies of analytical chemistry courses. Emphasizing laboratory-based, research-oriented, and interdisciplinary activities can enhance the quality of chemistry education and ensure the professional readiness of future chemistry teachers. Thus, analytical chemistry represents a significant resource for improving both the scientific and pedagogical dimensions of chemistry teacher preparation, which defines the scientific and practical value of the present article.

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