Foster young people's creativity and shape their competencies

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Abstract

Creative teachers are essential for fostering pupils' creativity. This paper explores the education of pre-service chemistry teachers, whose training encompasses both professional and pedagogical preparation. As part of their curriculum, they undertake courses such as *Laboratory Exercises in Analytical Chemistry*. Analytical chemistry, a branch of chemistry focused on the identification and quantification of substances, involves chemical analysis and the development of laws, criteria, and methods for determining qualitative and quantitative composition. Conducting laboratory exercises provides an optimal environment for enhancing the creative abilities of both pupils and pre-service teachers. This paper presents proposals, methodologies, and selected laboratory exercises aimed at fostering creativity and developing essential skills among pre-service chemistry teachers.

Keywords: Laboratory Exercise in Analytical Chemistry, Development, Creativity

1 Introduction

Creativity is specifically understood as the ability to think innovatively or to generate new ideas by combining existing elements in novel ways, whether in processes, objects, or knowledge. More recently, however, creativity and its practical implementation have come to be viewed as being in a dialectical relationship (McIntyre, 2011). Creativity (derived from Greek, meaning 'to create' or 'to make') can be characterized from multiple perspectives. From a didactic standpoint, it refers to the development of pupils' creative abilities. Creative teachers play a crucial role in the development of pupils' creativity because they create an environment that encourages open thinking, experimentation and innovation. Teachers' ability to introduce new approaches and stimuli supports pupils in developing knowledge, problem-solving skills, as well as expressive and collaborative abilities. Their creativity is

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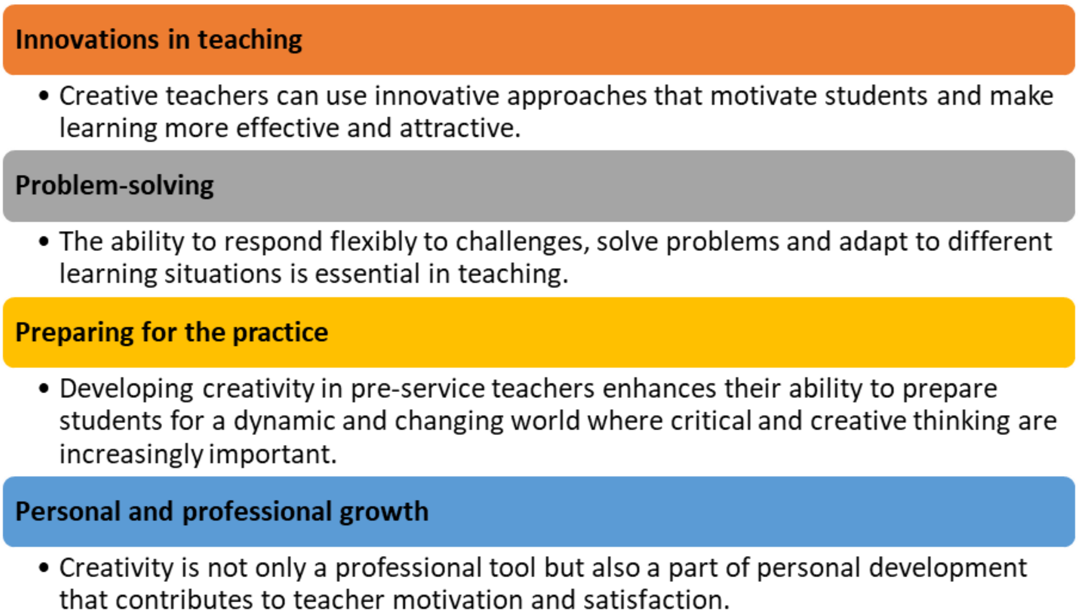
reflected in their use of modern methods and technologies, as well as in their capacity to recognize pupils' individual needs and inspire them to explore their potential. Creativity can be trained and taught in a variety of different ways, both through direct, active teaching of creativity concepts and techniques and through more passive and indirect means, such as the development of creativity-supporting contexts (Thornhill-Miller & Dupont, 2016; Hrmo, Miština, Jurinová, Krištofiaková, 2020). In the educational process, creativity represents a complex of special, attitudinal qualities of a pupil, a student, the ability to find new, original solutions, and all internal and external factors that determine the learning process (Turek, 1996).

The education of pre-service chemistry teachers at universities is focused on ensuring high-quality instruction in science disciplines. The goal is not only to equip future teachers with subject-specific knowledge but also to prepare them for practical teaching. This includes developing their ability to engage students, foster interest in science, and promote critical thinking. An essential aspect of their training is the development of pedagogical and didactic skills. These skills play a crucial role in fostering students' effective engagement in laboratory work, promoting active problem-solving in real-world contexts, and encouraging discussions on scientific issues. Developing creativity in students preparing for the teaching profession is crucial for a number of reasons (Scheme 1).



Scheme 1: Developing the creativity of pre-service chemistry teachers.

Creativity is the prime source of innovation, which in turn is acknowledged as the main driver of growth and wealth creation, as key to improvements in the social field and as an essential tool in addressing global challenges such as climate change, health care and sustainable development. Creativity is a multifaceted phenomenon that can be approached from many different angles (Thornhill-Miller et al., 2023). The point of creativity is for each individual to reach a higher level and also to be active in practical activities such as laboratory exercises. Current trends in education emphasise the promotion of interdisciplinary connections and the importance of understanding chemistry in the context of society, the environment and technology. Pre-service teachers need to be able to relate theory to practice, incorporate modern digital tools and respond to the diversity of learners in their classrooms. Quality education for pre-service teachers thus contributes to shaping a generation that will be better prepared to face global challenges.

The main aim of this paper is to analyse and present the educational process of pre-service chemistry teachers, focusing on the development of their creative abilities in the *Laboratory Exercise in Analytical Chemistry* course. This analysis includes identifying key elements that foster creativity, evaluating the effectiveness of educational strategies, and providing recommendations to enhance the creative potential of pre-service teachers.

1.1 Analytical chemistry and its role in chemical education

Analytical chemistry is the branch of chemistry concerned with the identification and determination of substances (chemical analysis), the search for and formulation of laws, criteria and methods enabling the determination of their qualitative and quantitative composition (Záruba, 2016). Analytical chemistry uses knowledge from other branches of chemistry, other natural science disciplines (biology, physics), and selected engineering disciplines to develop effective chemical analysis procedures.

Analytical methods and their instruction can serve both as a means and an object of teaching (e.g., studying the properties of substances and chemical reactions). Teaching analytical chemistry fosters students' creativity, enhances their problem-solving abilities in areas such as ecology, encourages the development of new approaches to problem-solving, and provides a broader perspective on chemistry and its connections with other disciplines.

For both theoretical and practical teaching, it is necessary for every teacher to take an interest in developing the creativity of their pupils, both in the form of the teaching aids used and the experiments conducted. Analytical chemistry, which is divided into qualitative and quantitative branches, offers the necessary foundation for both knowledge acquisition and the development of creativity of pre-service teachers and pupils. This approach emphasises the need for the purposeful and systematic development of creativity in the preparation of pre-service teachers, and chemistry education offers an ideal environment for fostering these skills through experimentation, analysis and synthesis of knowledge.

According to Lubart et al. (2013), based on multivariate models of creative potential), there are cognitive factors (e.g., divergent thinking, mental flexibility, convergent thinking, associative thinking, selective combination), conative factors (openness, tolerance of ambiguity, intuitive thinking, risk taking, motivation to create), and environmental factors that all support creativity.

Given the multi-dimensionality of the notion of creativity, the environment can positively influence and help develop creative capacities (Thornhill-Miller et al., 2023). Learning strategies can enhance students' critical and creative thinking skills in the acquisition of scientific knowledge (Zulyusri et al., 2023).

The theoretical foundations supporting creative and laboratory-based learning in future teachers are based on a number of pedagogical, psychological and didactical approaches. They are intended to emphasise the active participation of student-pre-service teachers in the learning process, experimentation and the development of higher cognitive skills. There are many theoretical backgrounds that support creative learning and learning based on laboratory work, all of which are applicable in laboratory work, such as constructivist theories of learning (Piaget, Vygotsky), Bloom's taxonomy of learning objectives, experiential learning theory (Kolb), heuristic learning, theories of creativity, situated learning, experiential learning theory, etc. The combination of the above theories promotes the acquisition of knowledge in pre-service teachers and the development of skills and attitudes necessary for their creative and effective teaching practice.

1.2 Laboratory Exercises in Analytical Chemistry in the preparation of pre-service chemistry teachers

The importance of laboratory exercises in chemistry for pre-service teachers is based on the development of professional and practical competencies. Pre-service teachers acquire the content knowledge, and the practical skills needed to convey it. They prepare for active teaching. Laboratory tasks and creative approaches prepare them to conduct lessons that will impact on pupils' active participation and knowledge development. Recent work conducted by the OECD exemplifies efforts aimed to foster creativity (and critical thinking) by focusing simultaneously on curriculum, educational activities, and teacher support and development at the primary, secondary, and higher education levels (Vincent-Lancrin et al., 2019; Saroyan, 2022).

Current analytical chemistry uses a variety of methods (Scheme 2) (Skong et al., 2021; Záruba, 2016).

Separation methods	•chromatographic methods - gas and liquid chromatography, • electromigration methods - electrophoresis.
Methods of measured analysis	•acidimetry, alkalimetry, complexometry, chelatometry, oxidimetry, reductometry, etc.
Thermal analysis	•thermogravimetry, differential thermal analysis, voluminometry, dilatometry.
Electrochemical methods	•potentiometry, amperometry, polarography, voltammetry, coulometry, electrogravimetry, conductometry, etc.
Optical metods	•flame photometry, fluorimetry, colourimetry, nephelometry, polarimetry, refractometry.
Spektroskopic methods	•atomic absorption and atomic fluorescence spectrometry, infrared, ultraviolet and Raman spectrometry, etc.
Rádioanalytical metods	•radiometric microanalysis, activation analysis, isotope analysis.
Mass spectrometry	

Scheme 2: Analytical chemistry methods.

Classical methods of qualitative inorganic analysis are based on the chemical reaction of the sample being analysed with a suitable reagent, which may be manifested by a change in colour, the formation or dissolution of a precipitate, the evolution of a gas, etc. (Čakrt et al., 1989). The longest-used methods of quantitative analysis are volumetric analysis (titration) and weighing analysis (gravimetry), which have been, and in many cases still are, the main working methods (Prudešová et al., 2016).

2 Methodology

The Laboratory Exercise in Analytical Chemistry (LACH) provides future graduates with new knowledge and practical skills, emphasising laboratory work in the chemical disciplines. The exercise is divided into two semesters and two parts Bachelor studies. Its division into qualitative analytical chemistry (LACH1), dealing with the determination of the type and number of constituents of the sample analysed (analytical proof) and quantitative (LACH2), which determines the amount and relative abundance of each constituent (analytical determination), provides all the prerequisites for the knowledge as well as the development of the creativity of the student-pre-service teachers (Table 1).

Laboratory Exercise in Analytical Chemistry 1 (LACH1)	*Laboratory Exercise in Analytical Chemistry 2 (LACH2)*
-Occupational health and safety in the chemical laboratory.	-Occupational health and safety,

- Separation of cations into classes by successive reactions with group test tubes. - -Separation and proof of cations of class I – a group of insoluble chlorides. - Separation and proof of cations of class II - a group of insoluble sulphates. - Separation and proof of cations subject to hydrolysis. - Separation of iron subgroup cations. - Separation of copper subgroup cations. - Separation of cations: Li^+, Na^+, K^+, NH_4^+, Mg^{2+}. -Proof of anions I. - II. - Final analysis of the unknown sample.	- Weighing in analytical chemistry. Weighing analysis. - Determination of the chemical composition of the sample. - Neutralisation titrations - acidimetry, alkalimetry. - Determination of BOD and COD of wastewater. - Oxidation-reduction titrations. - Analysis of unknown sample. - Precipitation titrations. -Argentometry, drinking water analysis, and determination of chlorides in the unknown water sample. - Complexometric titrations I. – II.

Table 1: Course information sheet Laboratory Exercise in Analytical Chemistry 1-2.

A key role of the above LACH 1-2 disciplines is the professional competencies of future chemistry teachers. Their acquisition will enable them to focus on developing critical thinking and creativity as well as pupils' independence within the educational process. This is one of the ways to activate their future learners, ultimately leading them to develop creativity and analytical-critical thinking and to acquire practical skills. One of the outcomes will then be the development of autonomy and self-assessment skills in pupils. These aspects are essential for preparing students – pre-service teachers for the challenges of the current working environment.

The aim of laboratory exercises in teacher training is that the student:
- apply the acquired knowledge and skills to experimental activities,
- to carry out proof reactions of cations and anions,
- know the principle of weighing analysis and evaluating its result,
- be familiar with the different types of volumetric analysis,
- perform titrations with the required precision and evaluate the result,
- use the acquired qualitative and quantitative analysis knowledge to determine an unknown sample.

The selected laboratory exercise in analytical chemistry oriented to the determination of chlorides is an example that can be included in several didactic concepts within problem-based learning and practical teaching. This type of exercise involves scientific investigation, analytical thinking and active student involvement. Its main orientation fits into the category of Problem-Based Learning (PBL). The PBL model is based on scientific inquiry and encourages students to solve a practical problem, collect data, analyse it, and draw conclusions. Laboratory work is an application of PBL and develops technical knowledge, critical thinking, and scientific work skills. By modelling innovative methods, pre-service teachers learn modern teaching methods that they can transfer to their practice and thus develop professional knowledge, a creative approach, and pedagogical skills.

3 Example of problem-based learning in a laboratory exercise

Problem-based learning is characterised by learning that involves problem-solving and creative thinking. It is a process that is based on the acquisition of knowledge and also on the acquisition of skills with work in the laboratory. An example of problem-based learning in the Laboratory Exercise in Analytical Chemistry is an integration of qualitative and quantitative analytical chemistry.

3.1 Argentometry: an example of a laboratory activity meant to foster creativity, critical thinking, and skill development

A laboratory exercise in analytical chemistry oriented towards argentometry allows students to deepen their expertise in volumetric analysis. The practical skills that students acquire—proper handling of chemicals, precision in performing experiments, and interpretation of results—are a creative approach to learning and problem-solving. Argentometry-oriented laboratory exercises include problems that stimulate creativity, design of experiments, analysis of real samples, and solving non-standard chemistry problems related to practice. This oriented approach teaches students to find solutions and apply knowledge in the context of environmental or everyday problems. Traditional educational approaches cannot meet the educational needs of our emergent societies if they do not teach, promote, and assess in line with the new learner characteristics and contexts of the 21st century (Sahin, 2009).

Educational objective:
-development of independent and creative thinking,
-education for the protection and creation of the environment,
-the importance of water and water resources for life,
-importance of drinking water, protection of the purity of drinking water sources,
-development of intellectual and manual skills (chemical calculations, preparation of solutions, working with pipettes and burettes, weighing),
- volumetric analysis and its principles,
-the importance of chloride determination in practice.

Basic knowledge and skills: chemical concepts: mass concentration, molar mass, measured solution, volume, precipitate, solubility product; *chemical properties of* AgCl, AgBr, etc.; *skills acquired:* pipetting, preparation of solutions (measured, standard).
Form of instruction: laboratory exercise
Experimental task: Chloride content: evaluation of water's hygienic safety and health.

3.1.1 Determination of chloride, according to Mohr

Principle:
Precipitation reactions that proceed rapidly and quantitatively enough are used for volumetric determinations or titrations (Čakrt et al., 1989). The precipitation method used is the volumetric argentometry method. Argentometry is based on the formation of sparingly water-soluble silver salts of halides (Cl^-, Br^-, I^-) and pseudohalides (CN^-, SCN^-) (Purdešová et al., 2016). The volumetric solutions used are 0.01 - 0.1 M solutions of $AgNO_3$ for direct titrations and 0.1 M KSCN or NH_4SCN for back titrations and for the determination of Ag+. NaCl or KCl are used to standardise the $AgNO_3$ stock solution. The end of titration is indicated by methods such as Mohr's, Fajans', and Volhard's (Purdešová et al., 2016).

Chemicals: 0,1M $AgNO_3$, 0,1M NaCl, indicator K_2CrO_4 (w=5%), chloride samples.

Materials: volumetric flask, holder, beaker, titration flask, stand, pipette, burette.

Procedure:
•Prepare a 0.1M standard solution by weighing the required amount of NaCl.
•Prepare a 0,1M volumetric solution of $AgNO_3$ by weighing the required amount of nitrate.
•For standardisation, pipette 25 cm^3 of standard NaCl solution into a titration flask, add 1 ml of the indicator (K_2CrO_4), adjust the volume to about 50 cm^3 with distilled water and titrate with a measured solution of $AgNO_3$ to a permanent reddish-brown colour.
•Repeat the titration 3-times and calculate the concentration of the measuring solution in $mol.dm^{-3}$ from the average consumption.
•Make up the unknown solution in the volumetric flask to 100 cm^3. Pipette 25 cm^3 into the titration flask and add 1 cm^3 of indicator (K_2CrO_4).
•Titrate the solution with standard $AgNO_3$ solution. When a slight brown colour (turbidity) appears, read off the volume on the scale.
•Repeat the titration 3 -times.
•Calculate the chloride content of the water sample from the average volume value.

Reactions:

$$NaCl + AgNO_3 \rightleftharpoons AgCl\downarrow + NaNO_3$$

$$Ag^+ + Cl^- \longrightarrow AgCl$$

Calculation:

$$c(Cl^-)=\frac{V_{pr}\,.\,c_{AgNO3}\,.\,35{,}45}{V_{\,vzorky}}\;[g.dm^{-3}]=\frac{3{,}14\,.0{,}05.35{,}45}{100}\;=\;55{,}65\;[g.dm^{-3}]$$

where
V (aver.) = average AgNO3 consumption in cm3
c(AgNO3) = concentration of AgNO3 (0.05 mol.dm-3)
V(sample) = volume of water sample in cm3
35.45 = molar mass of chloride M(Cl)

3.2 Problem-based learning procedure during the laboratory exercise

A problematic situation (Scheme 3) in the above laboratory exercise can be created by formulating a relationship for calculating the chloride concentration in a sample:

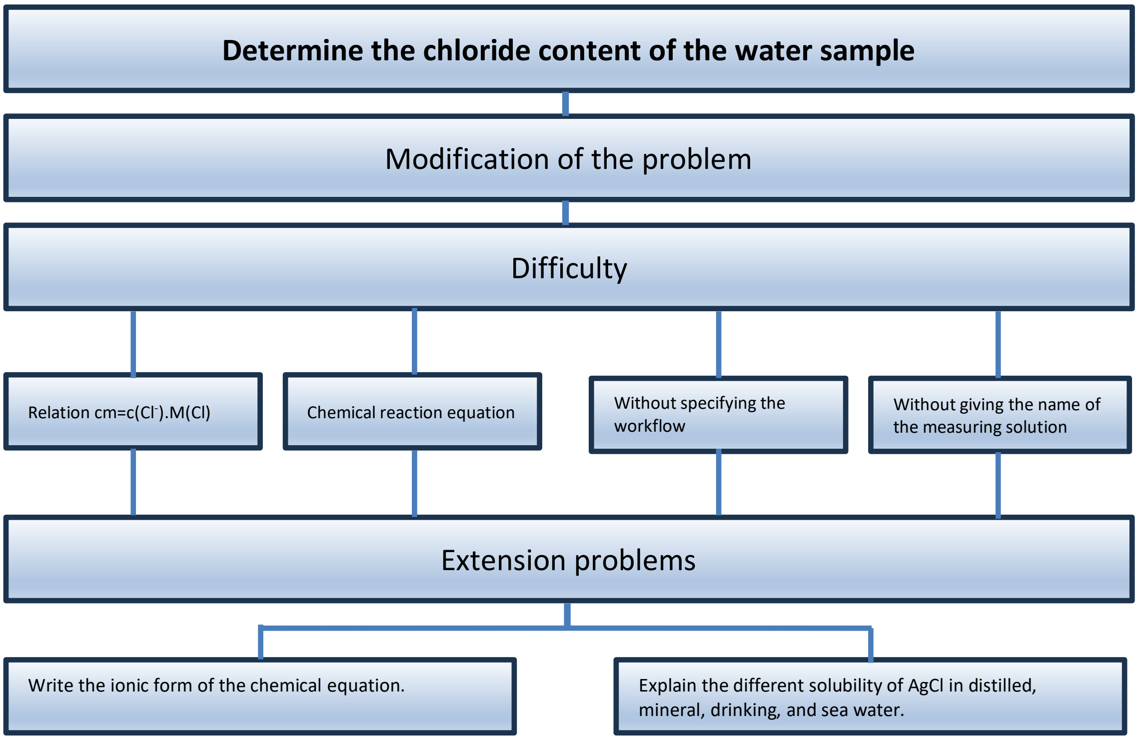
$$c_m = c(Cl^-) \times M(Cl)$$

where
c_m = mass concentration of chloride ($mg.dm^{-3}$) in the water sample
$c(Cl^-)$ = mass (mole) concentration of chloride ($mmol.dm^{-3}$) in the sample
M(Cl) = molar (mole) mass of chloride ($g.mol^{-1}$) =35,453 $g.mol^{-1}$

The substance concentration is calculated from the consumption of a measured solution of AgNO3.

$$c(Cl^-) = \frac{V_{s\,.}\,c(AgNO3)}{V_{sample}} \times 10^3$$

where
$c(Cl^-)$ = the concentration of chloride in the sample ($mmol.dm^{-3)}$
V_s = consumption of $AgNO_3$ measuring solution during sample titration (cm^3)
V_{sample} = the original sample volume (cm^3) during titration
$c(AgNO_3)$ = the concentration of the measuring solution $AgNO_3$ ($mol.dm^{-3}$)



Scheme 3: Experimental task.

The values of chloride concentration obtained by titration are compared with the valid Slovak technical norm (STN 75 7221, STN 75 7111) to determine the health safety of the analysed water sample with regard to chloride content. The problem modification (Scheme 3) can be supplemented with data such as the photosensitivity of the precipitate formed to light, which may lead to erroneous data and increase the demand for titration accuracy.
According to STN 75 7221 (1998) and STN 75 7111 (1999), which regulate groundwater and surface quality requirements, chloride (Cl^-) content is assessed as an important indicator of water quality. Chloride content limits may vary according to the intended use of the water (Table 2).

Drinking water	The maximum permissible chloride concentration is 100-250 mg/l (according to other standards such as EN ISO 10523 and EN 12519). The value depends on sensory characteristics (taste, odour) and health limits.
Surface water	For water quality categorisation according to STN: Class I (high quality): < 50 mg/l Class II (good quality): 50-100 mg/l Class III (acceptable quality): 100-250 mg/l Higher chloride values are typical for waters affected by anthropogenic activities, e.g., industrial discharges or the use of spreading salts.

Table 2: Surface and groundwater quality – chloride content (STN 75 7221, STN 75 7111).

4 Conclusions

The purpose of the laboratory exercises is to identify potential solutions and actions that contribute to the development of skills, critical thinking and creativity among students – pre-service teachers. The objective is to foster not only professional knowledge but also creative approaches and pedagogical skills, ultimately enhancing the quality and effectiveness of education. This objective extends to the *Laboratory Exercise in Analytical Chemistry* course, where a systematic and purposeful focus on the educational functions within the learning process is emphasized. Laboratory exercises play a crucial role in preparing pre-service chemistry teachers, as they deepen professional knowledge in analytical chemistry while providing practical experience for effective teaching. Through these exercises, students develop pedagogical skills, gain experience in presenting results, explaining chemical concepts, and preparing practical activities that are suitable for classroom instruction.

The course shapes pre-service teachers, equipping them with the ability to teach analytical chemistry theoretically and inspire pupils to develop a greater interest in chemistry through engaging and interactive laboratory activities. The problem-based learning approach discussed here serves as an example of how the skills acquired can be translated into innovative teaching methods.

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