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The education of pre-service chemistry teachers, the content of innovation, methods and forms during COVID-19

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Abstract

Nowadays, the importance of science teaching for the economic growth of countries is emphasized. The stimuli for implementing the innovation process in all areas of undergraduate teacher training are the traditions of university education and the dynamics of knowledge growth in science and technology. The university educational system is aimed to develop the quality of learning. The paper objectives are to inform about the e-learning course, which is located on the website of Constantine the Philosopher University in Nitra (Slovakia) entitled "Laboratory Practice in Analytical Chemistry". This course focused on analytical methods offered by the Department of Chemistry as part of the bachelor's degree program. This course of laboratory practice includes theoretical (studying texts) and practical parts (procedures). The Department of Chemistry, Constantine the Philosopher University in Nitra educates chemistry teachers with a combination of other disciplines for all types of schools. Education fluently develops the skills essential for a professional development pre-service teacher who lives in a technologically advanced world and economy. The current trends show that education and training pre-service chemistry teachers are changing and have a new cognitive strategy.

Keywords:
E-learning
Education
Laboratory Practice in Analytical Chemistry
Pre-service teacher

1 Introduction

Acquisition of scientific knowledge occurs in science education through theoretical and empirical cognition. The term electrochemistry is encountered in all areas of chemistry and other natural sciences, technical subjects, and everyday life. Electrochemistry is an established discipline with modern frontiers spanning energy conversion and storage, neuroscience, and organic synthesis (Kempler et al., 2021). Methods of electrochemical analysis are among the most common instrumental analysis methods, both in routine analysis and analytical control of production and in research laboratories and environmental management. Electrochemistry is the key to developing a sustainable CO_2-emission-free economy essential to mitigating climate change (Skong et al., 2018). Its use is not only in various sectors of the transportation sector (durable batteries and fuel cells, dense, electrolyzes to produce hydrogen gas) but also in chemical processes (Crabtree, 2019; Dowling et al., 2020; Minteer & Baran, 2020). Teaching interdisciplinary electrochemical topics requires addressing many challenges and identifying decisions. Nowadays, the importance of science teaching for countries' economic growth is emphasized. The labour market in Slovakia has changed, and so have the requirements of employers for future university graduates.
In this paper, we point out the importance of university education and training of pre-service teachers to apply selected interdisciplinary parts of chemistry in the discipline "*Laboratory Practice in Analytical Chemistry*" (LPACH). We focused on electrochemical analysis. The electrochemical analysis is based on measuring electroanalytical quantities and their changes. We demonstrate a part of a laboratory exercise using

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physicochemical methods - conductometry and conductometric titrations. Conductometry uses physicochemical methods, the relationship between the liquid, the analyte amount, and the electrochemical quantity. It is used in electroanalytical chemistry to measure the conductivity of liquids and titrate substances with the conductometric indication of the equivalence point. In this perspective, we highlight the core concepts of conductometry and discuss ways in which it is possible to educate students' pre-service teachers in this area. Finally, we outline example lectures oriented on conductometry, conductometric titrations and their use in practice. The presented topic can be found on Constantine the Philosopher University in Nitra (Slovakia) website, as one of the topics of the e-learning course "*Laboratory Practice in Analytical Chemistry*". We discuss new tools and approaches that can combine to prepare graduates for the profession of chemistry pre-service teachers. The application of interdisciplinary themes in science education increases students' motivation and interest in science disciplines such as chemistry. Through science education, they aim to deepen the interest of students, and pre-service teachers in chemistry-oriented education.

2 The e-learning education of pre-service chemistry teachers with theme "Laboratory Practice in Analytical Chemistry"

Education in the discipline "*Laboratory Practice in Analytical Chemistry*" that combines theoretical knowledge with practice is very current. Such a focused education can expand the knowledge of future graduates. At Constantine the Philosopher University in Nitra, great attention is paid to education in this area. The Department of Chemistry educates pedagogues-chemistry with other disciplines and is also educated in electrochemistry during their studies.

As part of the bachelor's degree program, the Department of Chemistry offers a course focused on analytical chemistry methods. Exercises entitled "*Laboratory Practice in Analytical Chemistry*" include theoretical (studying texts) and practical parts. They represent a tool that effectively manages and ensures the processes related to education by verifying theoretical knowledge in practice. Laboratory Practice in Analytical Chemistry aims to expand theoretical knowledge and acquire students´ practical skills. They are related to various areas of chemistry. In its information sheet, learning from multiple areas of chemistry is processed in an integrated way: *General Chemistry, Inorganic Chemistry, Organic Chemistry, Biochemistry, Physical Chemistry, Analytical Chemistry*, and other scientific disciplines. Their main aim is to monitor selected qualitative and qualitative indicators. For example, chemists familiar with homogeneous chemical reactions in beakers and flasks must translate their experience to heterogeneous reactions at interfaces while learning the fundamentals of transport and strengthening physics concepts (Han & Yin, 2016; Kempler et al., 2021), e.g., in a topic such as electrochemistry.

Nowadays, when the increasing number of COVID-19 diseases poses a health risk, we present e-learning as one of the forms of distance education. The University of Constantine the Philosopher in Nitra offers an e-learning educational portal in the LMS Moodle. This e-learning portal provides a space for the preparation of various courses and the subsequent creation of study materials in the course „*Laboratory Practice in Analytical Chemistry*", which we present.

The e-learning course combines the lectures (MS Word) with PowerPoint presentations, graphics, schemas, tests and supplementary materials (quizzes, files, control questions, polls, surveys). In the case of e-learning courses, there are several ways to process and present the curriculum, from the simple text presentation of the topic, through the interactive tutorials up to the complex simulations of real situations (Deena & Raja, 2017).

Students learning and the increased use of ICT predetermine the important role of e-learning in education (Larsen & Vincent-Lancrin, 2006; Azeiteiro & Filho & Caeiro, 2015; Sanganyado & Nkomo, 2018). The crucial factors for ICT education are teachers´ skills, content, and infrastructure that influence ICT promotion (Kanematsu and Barry, 2016).

3 Laboratory Practice in Analytical Chemistry

Laboratory Practice in Analytical Chemistry (LPACH) is a separate discipline. One of the topics that make it up is neutralization titrations. In addition, they are using physical and physicochemical methods for obtaining

analytical information. (Electrochemical interactions as a basis of analytical signal, Electrochemical analytical methods, Basic concepts of electroanalytical chemistry, Measurement of electrical quantities in a chemical laboratory).
The exercises build on students' theoretical knowledge acquired during the previous study. They enable the effective creation and dissemination of acquired knowledge. The practical skills are developed from the "*Laboratory Practice in Analytical Chemistry*" discipline. LPACH is a compulsory discipline intended for students in the 3rd year of bachelor's studies, with a time allowance of 4 hours/week. Each exercise has three essential parts: theoretical, practical, and feedback. During the practical part are evaluated selected procedures and skills. In the theoretical part and the feedback, the knowledge (tests, different types of tasks) is checked during laboratory exercises with e-learning. Tests and the testing process are essential and provide space for students´ active involvement in acquiring and disseminating knowledge. At the same time, it allows the teacher to monitor how students are progressing in learning and acquiring knowledge. At the same time, it will enable the teacher to watch how students learn and develop understanding.

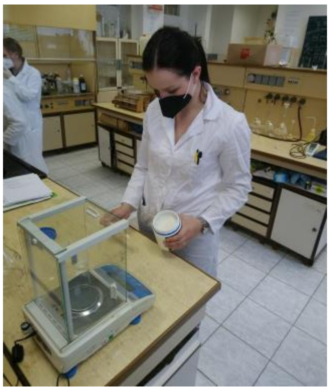

Fig. 1: Work during the "*Laboratory Practice in Analytical Chemistry*" focused on neutralization titrations.

In the course „*Laboratory Practice in Analytical Chemistry*", neutralization titrations are topics where students use electrochemical analytical methods (Fig. 1). It consists of laboratory exercises - acidimetry, alkalimetry, alkaline neutralization capacity and acid neutralization capacity wastewater. The electrochemical analysis measures electroanalytical quantities (current, resistance, capacity, etc.) and their change (Reguli, 2015). It uses the relationship between the liquid and the amount of the analysed substance and the electrochemical quantity (Reguli, 2015; Čakrt et al., 1989; Geffertová & Polóniová & Demianová, 2000). Different electroanalytical methods are used to determine electroanalytical quantities. They depend on the type of quantity that we monitor during the measurement (Geffertová & Polóniová & Demianová, 2000; Prudešová et al., 2016). For this aim, are using electrochemical analysis, e.g., conductometry. According to the processes involved in electrochemical analysis, the electrochemical reaction can be neglected. The cell current is dependent on the conductivity of the solution (conductometry), and the electrical resistance of the solution is measured (Reguli, 2015; Čakrt et al., 1989; Geffertová & Polóniová & Demianová, 2000).

3.1 Laboratory Exercises: Conductometry and Conductometric Titrations

Conductometry is one of the classical electrochemical methods. It determines the concentration of the sample to be measured based on the differential conductivity of the electric current (Garaj et al., 1977). It is based on the relationship between the electrical conductivity of the electrolyte and its concentration (Garaj et al., 1977; Geffertová & Polóniová & Demianová, 2000).
Example of a selected integrated laboratory exercise: Conductometry and Conductometric Titrations consist of the following parts: *motivation*-short introduction, *analogy,* and *interesting tasks T1a-T1c*, which have to be developed by the students after reading the issue from specialized literature. In this way, we have contributed to supporting the dissemination of innovation in chemistry teaching so that knowledge is based on their active activity, in which they naturally construct new knowledge.

Experiment implementation and justification of its relevance for the area of Chemistry.
Justification of theme selection: About the conductometry and conductometric titrations that students encounter during their studies, especially in other science disciplines. The usage of conductometry and conductometric titrations are very often concerned with their practical application. Conductometry is one of the electrochemical methods that determine the concentration of the measured sample based on the different conductivity of the electric current (Garaj & Bustín & Hladký, 1987). The motivation phase consists of a short introduction and examples of the conductometry and conductometric titrations of different chemical substances (acid and base solutions). Students have to prepare themselves to use specialized literature. They have to know what is meant the conductivity, how does the conductivity of selected substances (e.g., acids, bases) changes, and which the change depends on, what causes it, and which factors can affect the conductivity of chemical solutions. They will apply the experience gained from Physical Chemistry, Analytical Chemistry and Chemical Calculations, where students learn about conductometry. They have to use theoretical knowledge they have already gained (preparing solutions, measuring volume, standardization of solutions, working with indicators, and manipulating conductometer.

3.2 Task (T1) Conductometry, Factors Influencing it and its Use in Practice

Motivation

Conductometry is an electroanalytical method, its principles, and its use in practice. How are defined the resistance, direct conductometric analysis and conductometric titrations? Conductometry and its application in practice. What are changes in conductivity solutions of chemical substances, on which conductivity depends and affecting factors? Instruments for measuring conductivity. Requirements for conductivity cells used in electroanalytical methods - conductometry. Conductivity cell distribution based on design. Aids and equipment required for conductivity measurement of electrolyte solutions. Methods of determining the end point of conductometric titrations. These are questions and tasks, to which we have to respond. Conductometry is one of the frequently used analytical techniques (Bartušek & Pazourek, 2002; Paveleková, 2010). The number of conductometric measurements performed daily is enormous. It is mainly used in the food industry, healthcare, chemical and wood industries, chemical analysis, and water industries. It is one of the most widely used and reliable methods for monitoring the purity of water, whether distilled, demineralized, or feed water in circulation systems in the power industry (Vyskočil, 2019). Conductometric measurements also help in basic research. In analytical chemistry, conductivity measurement of solutions is used for direct analysis of electrolyte solutions, determination of the total concentration of solutions, quality control of solutions, monitoring changes in the course of electrolyte titrations, checking the quality of water, determining the concentration of very dilute solutions and coloured solutions. The provided examples are only a small part of the numerous applications of conductometric measurements. From the teacher's point of view, it is essential to present the conductometry and the conductometric titrations. What procedures and activating methods he will use.

Teacher's competencies: knowledge and understanding, skills and intellectual abilities.

TI: We study conductometry and its use in practice from the Chemistry literature. We focus on the conductometric titrations and measurement of conductivity in solutions. We will repeat the preparation of solutions of chemical substances (Feszterová, 2016). We compare the factors that influence the conductivity of chemical solutions and conductometric titrations. We indicate how and for which solutions of chemical substances the conductivity values will change. We compare the properties of acids (strong electrolytes and weak electrolytes.) and bases used to prepare solutions. We will try to answer (A) these questions through several tasks (T).

We divide the task into the following parts:

T1a Conductometry and measurement of conductivity.
T1b Indicate what conductivity measuring cells you know, how they are divided and their use.
T1c Conductometric titrations, titration curves and equivalence point.

3.2.1 T1a Conductometry and measurement of conductivity

Conductometry is an electrochemical analytical method that determines the electrical conductivity or resistance of electrolytes. Conductometric methods are based on the ability of an electrolyte solution (electrodes of type II) to conduct an electric current (Geffertová & Polóniová & Demianová, 2000).

We describe what causes the conduction of an electric current in a solution.

A1a: Conduction of electric current in solution is made possible by electrolytes. Electrolytes are solutions of acids, bases and salts (Geffertová & Polóniová & Demianová, 2000; Vyskočil, 2019). They are substances that dissociate in an aqueous solution into positive ions cations and negative ions anions. Their presence in the solution allows the conduction of an electric current (Geffertová & Polóniová & Demianová, 2000). By the action of an electric current, migration occurs in the electric field of the electrolyte the movement of ions to electrodes of opposite charge. In order to prevent electrolysis from taking place, an alternating voltage current at a frequency of 60 to 1000 Hz is used for conductometric measurements. With a DC voltage, polarization changes would occur at the electrodes, an increase in the polarization voltage relative to the insertion voltage, and then changes in the composition and concentration of the electrolytes.
The basis of conductometric measurement is Ohm's law (Geffertová & Polóniová & Demianová, 2000; Klein et al., 2009). The electrical resistance of an electrolyte solution layer between two electrodes with a certain area and distance is given by the relation (Geffertová & Polóniová & Demianová, 2000) (1):

$$R = \rho \frac{l}{S} \tag{1}$$

where R - resistance, ρ - specific resistance (constant of proportionality), l - distance between electrodes, S – area of electrodes

The term $\frac{l}{S}$ is constant for a given conductivity cell and is called the resistance constant of the conductivity cell (C).

3.2.2 T1b Indicate what conductivity measuring cells you know, how they are divided and their use

Measurement of conductivity is carried out using a conductometer and a conductivity measuring cell. A conductivity cell is part of equipment transforming conductivity (Vyskočil, 2019).
We provide how conductivity cells work and their distribution.

A1b: When measuring conductivity, a conductometer and a conductivity cell must always be present Conductometric measurements use conductivity cells of different shapes and sizes. They are made of glass, polyethylene or teflon. They have two inert electrodes, most often platinum placed opposite each other and fused to the cell´s walls. The electrode material must be chosen not chemically to react with the measured solution. Immersion conductivity electrodes are also often used, inserted into a beaker containing the solution to be tested. The conductivity of the solution between the electrodes is directly proportional to their area *S* and inversely proportional to their distance *l* (Geffertová & Polóniová & Demianová, 2000) (2):

$$G = \chi \frac{S}{l} \tag{2}$$

where G - conductivity [S], χ - specific conductance [$S.cm^{-1}$]

The ability of an electrolyte to conduct an electric current is not expressed by the resistance of the electrolyte, but by its inverse value-electrical conductivity (G) (Klein et al., 2009).

In addition to dividing conductivity cells into immersion and filling cells, they are divided according to their construction into (Vyskočil, 2019): *two-electrode* (which includes cells with three electrodes) and *four-electrode conductivity cells*.

The electrodes have the same area *A* and a constant distance *l* (1 cm). Specific conductance (conductivity) - is a constant characterizing the conductivity of a solution. It is determined dissociation degree of the substance, the concentration of ions in the solution, their strength, mobility, and the solution's temperature. It is the inverse of resistivity (3).

$$\chi = \frac{l}{\rho} \tag{3}$$

The specific conductance is determined in conductivity cells, characterised by the so-called resistance constant of the conductivity cell *C* (in m^{-1} or cm^{-1}). This conductometric constant is determined by measuring the conductivity *G* or resistance *R* of a solution with a known specific conductivity, dependent on the electrolyte's temperature and composition.

Conductivity cells are divided into immersion (the cell is immersed in the measured solution) and filling (the cell is filled with the measured solution) (Vyskočil, 2019).

*In terms of measuring cell used, conductometers are divided into (*Geffertová & Poloniová & Demianová, 2000; *Vyskočil, 2019):*
a) filling - the cell is filled with the measured solution;
b) immersion - the cell is immersed in the measured solution.

3.2.3 T1c Conductometric titrations, titration curves and equivalence point

Two methods are used in conductometric determinations: direct conductometric analysis and conductometric titration (Garaj et al., 1977; Geffertová & Polóniová & Demianová, 2000).
We compare the different methods. We share on what principle they work. We describe what the titration curve represents and what its shape is. How the end of the chemical reaction is revealed in conductometric titrations and detected. How the equivalence point (inflection point) is determined and what it represents. Finally, we design problems for selected conductometric resolutions.

A1c:

1. Direct conductometric analysis

In this method, the concentration of the sample is determined based on direct conductivity measurements (Geffertová & Polóniová & Demianová, 2000) (4):

$$c = k\chi \tag{4}$$

where c - sample concentration, χ - specific conductivity, k - constant of proportionality (determined by calibration measurement).

The quantitative evaluation of this method is made based on a calibration curve when the conductivities of standard solutions are measured with increasing concentration (Geffertová & Polóniová & Demianová, 2000). Then, a graphical dependence of conductivity on concentration is made from the measured values, the conductivity of the solution is measured, and its concentration is read from the graph (Geffertová & Polóniová & Demianová, 2000). This method is not very selective, and the determination of the concentration from measured conductivity is possible only in simple systems (one solute) (Geffertová & Polóniová & Demianová, 2000). In complex solutions, only the total ion concentration can be determined by conductivity measurement (Geffertová & Polóniová & Demianová, 2000; Klein et al., 2009).

2. Conductometric titration

Conductometric titration is based on measuring changes in electrical conductivity in the electrolyte solution during titration (Garaj, Bustín, Hladký, 1987; Geffertová & Polóniová & Demianová, 2000). It is mainly used to determine the equivalent point in neutralization, precipitation and substitution reactions (Geffertová & Polóniová & Demianová, 2000). It is titrated with more concentrated solutions so that the total volume of the solution does not change significantly (Geffertová & Polóniová & Demianová, 2000). From the consumption of the titration solution and the measured conductivity, a graphical dependence is constructed in the form of a titration curve, which in most cases is V-shaped (Geffertová & Polóniová & Demianová, 2000; Paveleková, 2010). At the intersection of the two lines, there is an equivalent point (Garaj & Bustín & Hladký, 1987; Geffertová & Polóniová & Demianová, 2000). From the point of view of accuracy and correctness of the determination of the equivalence point, it is preferable to use the weak base for the titration of weak acids (Geffertová &Polóniová & Demianová, 2000). Conductometric titrations have the advantage of determining the concentration of very dilute solutions with the same accuracy as more concentrated solutions (Geffertová & Polóniová & Demianová, 2000). Furthermore, conductometric titration can be used to titrate very weak acids and bases that give inaccurate results when indicated potentiometrically or visually (Geffertová & Polóniová & Demianová, 2000; Paveleková, 2010).

Conductometry is not limited to acid-base titrations. It can also be used to monitor precipitation, complexometric and redox titrations (Geffertová & Polóniová & Demianová, 2000; Klein et al., 2009). A mixture of strong, and weak acids as well as coloured and turbid solutions, can also be titrated conductometrically (Geffertová & Polóniová & Demianová, 2000; Paveleková, 2010). Strong electrolytes (HCl, H_2SO_4, HNO_3, NaOH, KOH, and most salts) are wholly dissociated in the solution. In contrast, weak electrolytes (H_2CO_3, H_3PO_4, NH_4OH, and most organic acids) are only slightly dissociated in solution, and most of the electrolyte is present as electroneutral molecules (Geffertová & Polóniová & Demianová 2000; Klein et al., 2009; Paveleková, 2010).

Conductometric determination of selected chemical solutions in practice:
Conductometric determination of the purity of distilled water by determining the capacity of the conductivity cell.
Conductometric determination of the concentration of NaOH (KOH) in the sample solution.
Conductometric determination of the concentration of CH_3COOH in a sample of vinegar.

4 Conclusion

We point to the interconnectedness of science education (chemistry, physics, environmental science), specifically in the area related to electrochemistry. One way to contribute to the effective teaching of this issue is to use innovative approaches in education, which are motivating and mainly activating. An example of such an innovative approach in chemistry is the integrated laboratory exercise, which combines chemical, and physicochemical experiments with the construction of physical knowledge. Given the importance of electrochemical science, electrochemistry education deserves reinvigoration and reinvention to meet the needs of the 21st century (Kempler at al., 2021).
The aim is to integrate knowledge and work methods that can be used appropriately during the laboratory exercise and through e-learning. In a selected laboratory exercise, we focused on integrating knowledge in the field of conductometry and conductometric titrations in solutions of chemicals (acids, bases) with different concentrations.

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