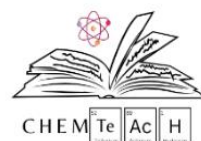




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Modern Chemistry Teaching

COMPETENCIES AND PEDAGOGICAL APPROACHES

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Banja Luka, 2025

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Modern Chemistry Teaching

COMPETENCIES AND PEDAGOGICAL APPROACHES

A guide for chemistry teachers providing theoretical and practical support for developing competencies and modern pedagogical methods

Electronic edition

Erasmus+ Project

Improvement the quality of chemistry teaching in VET in
Bosnia and Herzegovina

101129417-ERASMUS-EDU-2023-CB-VET

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This manual was developed within the framework of the Erasmus+ project “Improving the Quality of Chemistry Teaching in Vocational Education in Bosnia and Herzegovina – ChemTeach” (101129417-ERASMUS-EDU-2023-CB-VET), which aims to empower chemistry teachers to apply modern approaches in education. The project is implemented through cooperation among vocational secondary schools, universities, and employers, with a focus on developing teaching competencies and enhancing the quality of science education.

The project coordinator is the Slovak University of Technology in Bratislava, while the team from the Faculty of Natural Sciences and Mathematics at the University of Banja Luka, as the author of this manual, leads the activities in Bosnia and Herzegovina in cooperation with three schools from Banja Luka: the Gymnasium, the Medical School, and the Technological School. Project activities also involve partners from Slovakia and the Czech Republic, with the goal of exchanging best practices and developing modern educational materials.

This manual is intended for teachers of chemistry and related subjects, with the aim of providing both theoretical and practical support for the implementation of high-quality, contextualized, and competence-oriented chemistry teaching.

Banja Luka, May 2025

Ovaj priručnik nastao je u okviru Erasmus+ projekta "Unapređenje kvalitete nastave hemije u stručnom obrazovanju u Bosni i Hercegovini – ChemTeach" (101129417-ERASMUS-EDU-2023-CB-VET), čiji je cilj osnaživanje nastavnika hemije za primjenu savremenih pristupa u obrazovanju. Projekat se realizuje kroz saradnju srednjih stručnih škola, univerziteta i poslodavaca, sa fokusom na razvoj nastavničkih kompetencija i unapređenje kvaliteta nastave prirodnih nauka.

Koordinator projekta je Slovački tehnički univerzitet iz Bratislave, a tim Prirodno-matematičkog fakulteta Univerziteta u Banjoj Luci, kao autor ovog priručnika, vodi aktivnosti u Bosni i Hercegovini u saradnji sa tri banjalučke škole: Gimnazijom, Medicinskom i Tehnološkom školom. U projektne aktivnosti uključeni su i partneri iz Slovačke i Češke, sa ciljem razmjene dobrih praksi i izgradnje savremenih obrazovnih materijala.

Priručnik je namijenjen nastavnicima hemije i srodnih predmeta, s namjerom da im pruži teorijsku i praktičnu podršku za realizaciju kvalitetne, kontekstualizovane i kompetencijski orijentisane nastave hemije.

Banja Luka, maj 2025. godine

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In today's society, science is the main driver of economic progress and a key factor in a community's capacity to innovate and create future jobs. Chemistry, as a fundamental natural science, holds a unique place in this process—its principles and laws permeate daily life, industry, medicine, agriculture, environmental protection, and many other fields.

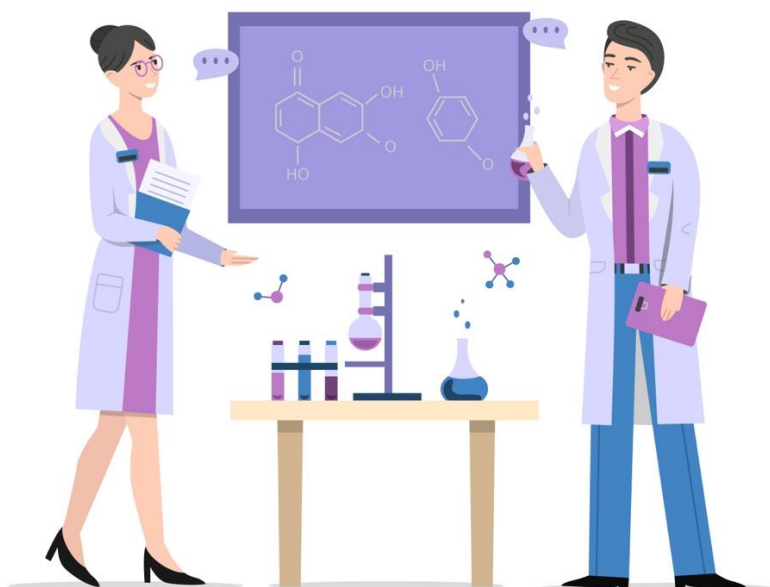
Despite its importance, modern education faces the challenge of delivering relevant scientific knowledge and skills in ways that enable students to understand the complexity of the world around them and motivate them to pursue careers in science. Issues such as environmental protection, sustainable development, energy transition, food security, and public health require educated individuals who can comprehend and critically assess scientific information.

Accordingly, the education system must align science education with the needs of contemporary society and enable students to develop scientific literacy—the ability to understand scientific phenomena, use evidence when making decisions, and act responsibly as citizens in a modern world.

This guide for chemistry teachers was developed as part of the Erasmus+ project “Improving the Quality of Chemistry Teaching in Vocational Education in Bosnia and Herzegovina” (ChemTeach). Its purpose is to support high-quality chemistry education and to address the challenges of teaching in the field of natural sciences. It offers theoretical foundations and practical guidelines to help teachers plan and deliver instruction, build student competencies, and prepare learners to apply chemistry in real-world contexts.

At the core of this guide is the call for a pedagogical shift—from traditional, content-reproduction teaching to active learning that

encourages understanding, inquiry, connections to everyday life, and the application of knowledge in new situations. The ultimate goal is for students to perceive chemistry not as a collection of abstract facts, but as a practical tool for solving problems related to health, environment, consumption, nutrition, energy, and many other areas of life.



The value of experimental work in chemistry education has long been recognized—not only for acquiring practical skills but also for fostering logical thinking and scientific methodology. At the same time, modern digital tools, including those using artificial intelligence, offer new opportunities for personalized learning, virtual experiments, and interactive exploration of chemical phenomena.

This guide also addresses scientific literacy as a central goal of modern science education. A scientifically literate person not only understands basic concepts and laws but can also apply them critically in everyday life, make informed decisions based on evidence, and understand the

broader societal implications of science and technology. Given its interdisciplinary nature and connection to daily life, chemistry as a school subject holds great potential for developing these competencies.

Furthermore, the guide opens space for reflecting on the place of chemistry in curricula and the challenges teachers face in its instruction—from limited material resources to outdated program content and declining student interest in science. One of the key aims of this material is to support teachers in designing learning experiences that go beyond the mere transmission of information, focusing instead on functionality, context, and the development of competencies.

We believe this guide will serve as a valuable resource for chemistry teachers in their daily work and contribute meaningfully to the ongoing reform of science education. Its purpose is to empower teachers as agents of change—because only through high-quality, modern chemistry education can we build the foundation for a knowledge-based society equipped to tackle the challenges of today and tomorrow.

Based on the needs of modern society and the challenges of science education, and drawing on the experiences and recommendations from the Erasmus+ ChemTeach project, this guide aims to:

Support chemistry teachers in understanding the educational and societal role of chemistry, by reflecting on its significance for scientific progress, daily life, innovation, and sustainable development.

Empower chemistry teachers to develop students' scientific literacy, critically address pseudoscientific narratives, and promote the scientific method in teaching.

Provide a theoretical and didactic framework for applying modern teaching approaches, with a focus on active, inquiry-based, and problem-oriented learning that is relevant and motivating.

Enhance teachers' competencies in planning and implementing contemporary curricula, including learning outcomes, skill development, interdisciplinarity, evaluation, and digital technologies.

Support teachers in selecting and applying teaching methods that foster both generic and subject-specific competencies such as critical thinking, collaboration, communication, and responsibility.

Refresh the professional role of chemistry teachers through good practice examples, reflection on the use of AI in education, and affirmation of the teacher as a driver of change in modern society.

THE ROLE AND POSITION OF CHEMISTRY IN THE EDUCATION SYSTEM

In modern society, science is a key driver of economic, social, and technological development. Among the natural sciences, chemistry holds a special place as it bridges fundamental knowledge with practical application, and has the capacity to explain many phenomena of everyday life, industrial processes, and contemporary challenges such as climate change, sustainable development, and the preservation of human health and the environment. In this context, chemistry education must have a clearly defined and significant role within the education system.

CHEMISTRY AS A FOUNDATION OF SCIENTIFIC LITERACY

The role of chemistry as a school subject goes far beyond the mere transmission of knowledge—it is fundamentally tied to the development of students' scientific literacy. According to the OECD, scientific literacy involves the ability to understand, apply, and use scientific information to make informed decisions. In this regard, chemistry helps students connect theoretical knowledge with everyday experiences, think critically, and solve real-world problems.

Whether a student becomes a scientist, healthcare worker, engineer, farmer, or simply a citizen who makes responsible choices regarding health and the environment, basic knowledge of chemistry is essential for life in modern society. Traditionally, chemistry education in general and vocational secondary schools is organized by school year, following the logic of chemistry as a scientific discipline. In the first year, students

study general and inorganic chemistry; in the second, physical and analytical chemistry; in the third, organic chemistry; and in the fourth year, natural product chemistry and biochemistry. This structure supports gradual and in-depth knowledge acquisition, yet there remains room for improvement—particularly in terms of connecting content with everyday life and integrating it with other scientific disciplines.

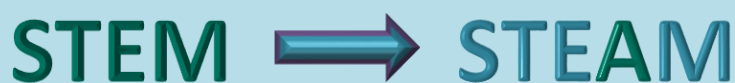
Contemporary curricula in many European Union countries increasingly organize chemistry teaching around domains or thematic areas, such as “matter and change,” “energy and chemical reactions,” “chemistry and the environment,” or “chemistry and health.” This approach, which will be further discussed later in the guide, provides greater flexibility, better integration of content with real-life contexts, and fosters the development of so-called transversal competencies.

INTERDISCIPLINARY NATURE OF CHEMISTRY AND ITS CONNECTION TO OTHER SCIENCES

Chemistry is not an isolated discipline—it lies at the core of STEM fields (science, technology, engineering, and mathematics). Its strong connections to biology, physics, medicine, ecology, and engineering make it an ideal foundation for developing interdisciplinary learning. Teachers can, for example, link topics such as photosynthesis (chemistry and biology), thermodynamics (chemistry and physics), or environmental pollution and protection (chemistry and ecology). This approach allows students to understand chemical concepts in a broader context, develop a deeper understanding of natural phenomena, and connect school learning to real-world challenges.

By expanding this approach to include the arts—moving from STEM to STEAM—teaching becomes even richer, encouraging creative

expression. Integrating elements such as visualization, design thinking, and creative problem-solving enables students not only to gain a deeper understanding of chemistry within a broader scientific framework, but also to interpret and apply that knowledge in imaginative and meaningful ways. For example, students may design eco-friendly products, create infographics to represent complex scientific data, or develop multimedia presentations about chemical processes that impact everyday life.



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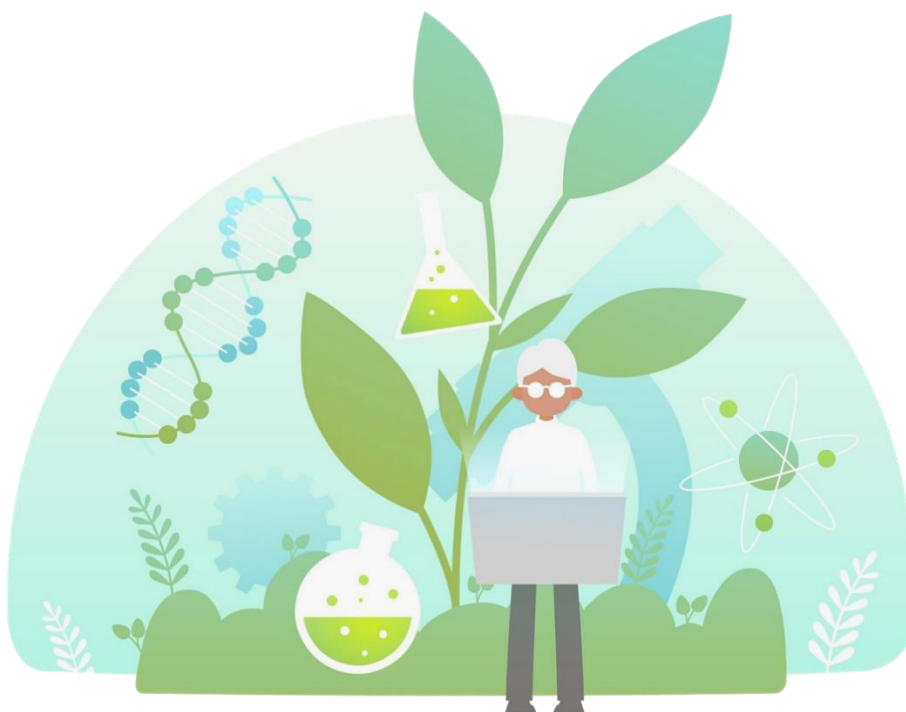
Applying this kind of interdisciplinary and creative approach helps students develop deeper scientific understanding, fosters innovation, and bridges school learning with real-life issues. STEAM education nurtures both analytical and creative thinking—skills that are essential in today's dynamic world.

PEDAGOGICAL ASPECTS OF CHEMISTRY TEACHING

The role of the chemistry teacher is to actively engage students in the learning process through experimental work, discussions, projects, and the use of modern technologies. Experiments enable students to visualize abstract phenomena, test hypotheses, and develop scientific thinking skills. In modern education systems, the emphasis is placed on active learning and the development of competencies, rather than

merely memorizing facts.

In addition to experiments, digital tools, simulations, and virtual laboratories are increasingly used, allowing for a more inclusive approach and compensating for the lack of equipment in schools. Furthermore, modern teaching involves fostering generic competencies such as problem-solving, collaboration, communication, and critical thinking. Artificial intelligence has potential to support teacher to individualize and focus on student-centered approach.



CHEMISTRY IN A BROADER SOCIETAL CONTEXT

Learning chemistry must be connected to real-life contexts – food

chemistry, chemistry in the household, cosmetics, medicines, detergents – these are all topics that students can explore and analyze. Linking theoretical knowledge with everyday life examples increases motivation, promotes deep learning, and strengthens awareness of the importance of science.

Furthermore, through chemistry education, students should develop a sense of responsibility toward the environment and understand the principles of sustainable development. For example, introducing topics such as green chemistry and the circular economy into chemistry teaching can help foster environmental awareness and encourage students to follow sustainability related career path.

FROM TRADITIONAL TO ACTIVE LEARNING

TRADITIONAL MODELS OF CHEMISTRY TEACHING

Traditional models of chemistry teaching are based on a frontal approach in which the teacher dominates the process as the primary source of knowledge, while students are passive listeners. The teaching is usually focused on theoretical information, using methods such as lectures and content reproduction.



Figure 1. Student-centered learning (source: educationevolving.org)

Students are encouraged to memorize definitions and formulas without a deeper understanding of context or practical application. The lack of opportunities to ask questions, explore, or express their own ideas limits the development of critical thinking and deeper comprehension. Although this approach may be effective for acquiring basic facts, it does not foster the skills needed to apply scientific concepts in real-life situations.

TRANSITION TO STUDENT-CENTERED LEARNING

Modern educational approaches aim to shift the focus from the teacher to the student. In this model, the student becomes an active participant in the learning process, while the teacher takes on the role of facilitator, supporting student autonomy and engagement. Learning is tailored to the individual needs, interests, and abilities of students, and the teaching content is connected to real-world situations. In chemistry education, this means involving students in experiments, projects, and interdisciplinary tasks through which they develop analytical thinking, ask questions, and actively explore the phenomena around them.

ACTIVE TEACHING METHODS – ADVANTAGES AND CHALLENGES

Active learning methods, such as experimental work, teamwork, and project-based instruction, enable students to acquire knowledge through hands-on activities. This approach fosters the development of both practical and cognitive skills, as well as the ability to apply scientific concepts in various contexts. However, implementing these methods requires additional resources, teacher professional development, and access to modern teaching tools and technologies. Additionally, successful active learning assumes that students are willing to take

greater responsibility for their own learning, which can be challenging for those accustomed to traditional models. Organizing and monitoring activities in large classrooms can also be demanding.

THE ROLE OF THE TEACHER AS A FACILITATOR

In actively oriented teaching, the teacher is no longer merely a transmitter of knowledge, but a support to students in the process of independent discovery and understanding of content. As facilitators, teachers create an environment that encourages exploration, problem-solving, questioning, and teamwork. In chemistry teaching, this means encouraging students to analyze experiments, apply acquired knowledge, and connect it with everyday life. The teacher's role also includes motivating students and providing tools and strategies for developing critical thinking and independence. Teachers who apply this approach need to be flexible, ready to adapt teaching methods, and continuously develop their professional competencies in order to create a dynamic and supportive classroom environment.

DEVELOPMENT OF SCIENTIFIC LITERACY

In the modern society, based on knowledge and rapid technological development, scientific literacy becomes a key competency of an individual. Science is one of the main drivers of economic development and the foundation for innovation and new jobs. At the same time, intensive exploitation of natural resources and industrial production lead to numerous challenges – ecological, climatic, health, and economic. In this context, the educational system needs to respond to contemporary needs through the development of scientific literacy.

COMPONENTS OF SCIENTIFIC LITERACY

According to the OECD definition, scientific literacy implies the ability of an individual to engage with scientific topics and problems, use scientific evidence in decision-making, and understand basic concepts and processes. A scientifically literate person:

- Understands basic concepts and laws of natural sciences;
- Asks questions, analyses data, and interprets scientific results;
- Applies scientific knowledge in everyday life and in a societal context.

Scientific literacy is not only about knowing definitions, but also about understanding how science works, its role in society, and how knowledge is responsibly applied. This includes:

- Understanding scientific research methods: hypotheses, experiments, experimental conditions, interpretation;
- Knowing basic ethical principles: responsibility, academic

integrity, respect for intellectual property;

- Using scientific arguments in everyday situations;
- Responsible use of scientific knowledge and technology in the interest of the community.

EXAMPLES OF ACTIVITIES

Analyze media content that includes scientific claims (advertisements, articles, blogs). Are the claims evidence-based?

Organize a workshop: How is chemistry used in the household (detergents, preservatives, cosmetics)?

Design an experiment that demonstrates a phenomenon from everyday life (e.g., the acidity of cleaning products).

DISCUSSION

Why is it important to distinguish scientific from non-scientific sources of information?

How does scientific literacy influence our everyday decisions?

SELF-ASSESSMENT

To what extent do you agree with the statement: "I can recognize when a claim is pseudoscientific"?

THE ROLE OF CHEMISTRY IN EVERYDAY DECISION-MAKING

Knowledge of chemistry supports informed decision-making regarding health, nutrition, hygiene, and environmental protection. However, chemistry education is often overly theoretical, lacking sufficient connection to real life. The absence of experiments, integration with other subjects, and student career orientation contributes to declining interest in chemistry and STEM fields.

Chemical knowledge is essential for the energy, food, and pharmaceutical industries, but also for everyday life. This means that high school students should understand the practical value of chemistry, which helps answer questions such as: "Which soap is more effective?", "Why does food spoil?", or "How does a descaling agent work?" – opening up space for inquiry-based learning.

EXAMPLES OF ACTIVITIES

Research task: Comparing water from different sources (pH, hardness, color, odor).

Debate: "Are all chemicals harmful?" – students defend different viewpoints using scientific arguments.

Product label analysis: Which chemical substances are used and why?

DISCUSSION

What are examples of positive applications of chemistry in everyday life?

What would the world look like without chemistry?

SELF-ASSESSMENT

To what extent do you understand the ways chemistry affects your everyday life?

ETHICS IN SCIENTIFIC RESEARCH

Developing scientific literacy also includes understanding the ethical aspects of research. Science must comply with laws, ethical principles, and the protection of human rights and the environment. Students should adopt principles of responsible experimental work, source verification, and ethical presentation and interpretation of results.

Ethics involves academic integrity, respect for copyright, and awareness of the potential consequences of scientific discoveries. Chemistry, as an experimental science, provides a solid foundation for developing these values through research activities and teamwork.

EXAMPLES OF ACTIVITIES

Simulation of an ethics committee: students decide on the ethics of an experiment based on a case study.

Analysis of real examples of misuse of science (e.g., pollution, corporate interests).

Creating a poster on scientific responsibility and presenting it at school.

Students should distinguish between unintentional errors in research and deliberate manipulation. In chemistry classes, it is important to

encourage a culture of openness, acknowledging mistakes, and continuous learning — which forms the basis for scientific development.

DISCUSSION

Do scientists bear responsibility for the application of their discoveries?

Can science be neutral in relation to the values upheld by a society?

Who is responsible when scientific facts are misinterpreted in the media – scientists, journalists, or readers?

Is there a boundary between science and personal beliefs?

SELF-ASSESSMENT

Do you take into account ethical rules and the reliability of sources during research?

Developing scientific literacy is not only the task of science teachers but a shared goal of education. Chemistry teaching provides a unique opportunity for students to develop analytical thinking, responsibility, and the ability to make informed decisions — qualities that are essential for active citizenship in modern society.

THE SCIENTIFIC METHOD AND DISTINGUISHING SCIENCE FROM PSEUDOSCIENCE

APPLICATION OF THE SCIENTIFIC METHOD IN CHEMISTRY TEACHING

The scientific method represents a systematic approach to studying phenomena, based on asking questions, formulating hypotheses, collecting and analyzing data, drawing conclusions, and evaluating results. By using the scientific method, students develop critical thinking and problem-solving skills. Chemistry teaching provides an excellent opportunity to apply the scientific method through experimentation, observation, and formulation of conclusions. Students learn how to pose research questions, plan experiments, analyse results, and reflect on the applications of scientific knowledge.

EXAMPLES OF ACTIVITIES

Design and conduct an experiment: *"Which detergent removes stubborn stains most effectively?"*

Research question: *"How does temperature affect the rate of dissolution?"*

DISCUSSION

Which stages of the scientific method do we use in everyday life without even realizing it?

SELF-ASSESSMENT

To what extent are you able to independently plan and carry out a simple chemistry experiment?

RECOGNIZING PSEUDOSCIENTIFIC CLAIMS

Distinguishing between scientific and pseudoscientific claims is an important part of scientific literacy. Pseudoscientific claims often imitate the language of science, but they are neither presented systematically nor based on verifiable evidence.

Therefore, it is necessary to develop students' ability to recognize the characteristics of pseudoscience: lack of verifiable evidence, reliance on authority without argumentation, use of scientific language without substance, and ignoring opposing evidence. By introducing everyday examples, such as advertisements for "miracle products" or unverified claims on social media, students can critically analyse the information surrounding them.

EXAMPLES OF ACTIVITIES

Researching a Controversial Topic (e.g., vaccination, GMOs, climate change) – students work in pairs to gather scientific and pseudoscientific sources, analyze the differences, and present their conclusions.

Analysis of Online Video Content: Are the claims evidence-based?

Debate: “Should we believe everything that is claimed to be scientifically proven?”

DISCUSSION

How to distinguish scientifically valid information from manipulative claims?

SELF-ASSESSMENT

Are you confident in your ability to recognize pseudoscientific claims?

EVALUATION OF SCIENTIFIC LITERACY IN CHEMISTRY TEACHING

Introducing tasks that require the application of the scientific method and critical analysis of pseudoscientific claims contributes to the development of scientific literacy. Evaluation should encompass not only acquired knowledge but also the ability for analytical thinking, argumentation, and ethical reflection.

Activities may include creating mini-projects, writing scientific reviews, presenting research results, and reflecting on the learning process. This way, chemistry knowledge is connected to broader contexts, and competencies necessary for responsible and informed action in modern society are developed.

EXAMPLES OF ACTIVITIES

Poster creation: "How to Recognize Pseudoscience?"

Research task: Analysis of the composition of a popular "detox" drink – are the claims justified?

DISCUSSION

What would a school look like that regularly and obligatorily develops scientific literacy across all subjects?

SELF-ASSESSMENT

How confident are you in your ability to evaluate the reliability of a scientific claim?

ACTIVE LEARNING IN CHEMISTRY

PARADIGM SHIFT IN LEARNING

Traditional teaching, where students passively receive ready-made information, is increasingly being replaced by an approach that places the student at the centre of the learning process. In modern education, students actively participate in lessons through various forms of cognitive engagement, while the teacher takes on the role of facilitator and mentor. This approach enables deeper understanding of the material and development of competencies applicable in everyday life and future work.

Active vs. Passive Learning

Traditional, passive learning approaches often involve frontal teaching where the teacher transmits knowledge and students reproduce it. In such a model, students mainly listen, take notes, and prepare for tests that measure the number of facts memorized. Although this method can yield short-term results, it rarely contributes to deeper understanding, knowledge integration, and skill development.

On the other hand, active learning involves students participating in the educational process through activities that require thinking, analysis, collaboration, and application of knowledge. Instead of being passive recipients of information, students become active creators of knowledge. This approach enables better understanding of concepts, development of metacognitive skills, and long-lasting knowledge retention. The following table shows the main differences between passive and active learning.

Table 1. Key Differences Between Passive and Active Learning

Passive Learning	Active Learning
Focus on transmitting ready-made information	Focus on inquiry and knowledge construction
Students listen and take notes	Students ask questions and discuss
Reproduction of knowledge	Application, analysis, and synthesis of knowledge
Teacher dominates the process	Teacher guides
Limited interaction	Active mutual collaboration
Short-term memorization	Long-term understanding

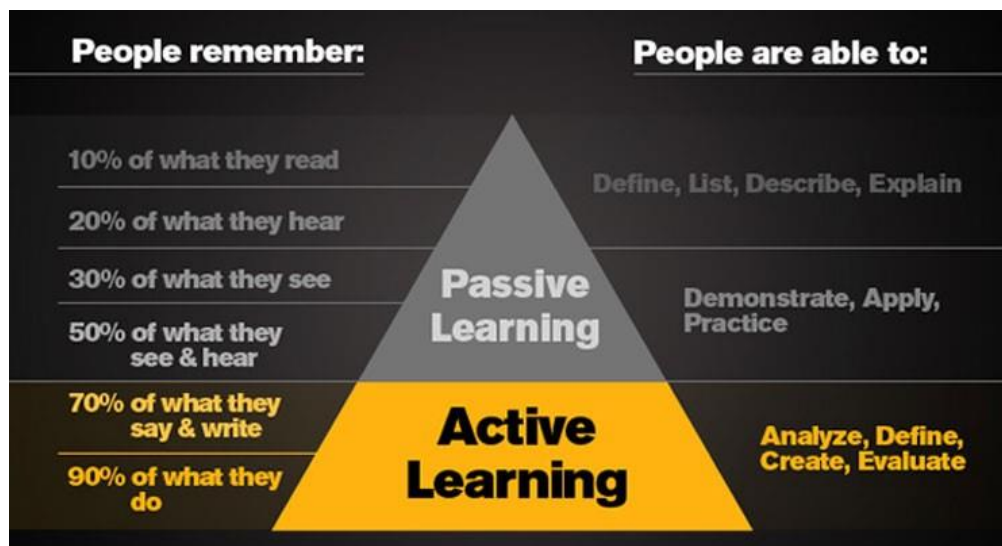


Figure 2. Passive vs Active learning. (source: teachonline.asu.edu)

What Is Active Learning?

Active learning encompasses a variety of approaches and methods that involve the active engagement of students in the learning process. Its key characteristics include independent inquiry, mutual interaction,

connection with everyday experiences, and reflection. Students do not receive knowledge passively; rather, they construct it through their own experiences, using available information, experiments, discussions, and problem-solving.

EXAMPLES OF ACTIVITIES

Testing for the Presence of Starch in Various Foods

Students, working in groups, design and conduct an experiment using iodine solution and household samples (e.g., potato, bread, apple, pasta).

DISCUSSION

Which samples gave a positive reaction for starch, and why?
How do we interpret the color changes in the reaction between iodine and starch?

SELF-ASSESSMENT

How engaged were you in planning and conducting the experiment?

Can you name at least one way to further investigate the role of starch in nutrition or chemical processes?

Why Is Active Learning Important in Chemistry?

- Chemistry is a conceptually demanding, experimental science. In chemistry classes, students not only acquire theoretical knowledge but also develop the skills needed for practical application of that knowledge. Students are expected to actively participate in the investigative process, reflect on the results of their experiments, and connect theory with practice. Active learning provides students the opportunity to engage in experiments, analyze chemical reactions, and develop critical thinking.
- Active learning plays a key role in the development of chemical literacy, which means the ability of students to understand, analyze, and apply chemical concepts in everyday life situations. Through various activities such as experiments, research, and discussions, students not only better understand chemical concepts but also develop skills that help them recognize chemical phenomena in their surroundings. Active learning enables students to learn from their own experience, increasing their ability to apply chemical principles in real situations.
- Through active learning, students develop scientific thinking and the ability to draw conclusions based on analyses and experiments. This approach allows students to face real problems, consider different possibilities, and learn how to make informed decisions based on available data. Active learning encourages students to ask questions, investigate causes and effects of chemical reactions, and develop skills for solving complex problems.
- Chemistry is closely connected to everyday life, and understanding basic chemical principles helps students better

understand the world around them. Active learning allows students to learn by applying chemistry to everyday examples and situations, such as household experiments, analysis of food products, or understanding ecological challenges. This links chemistry to real life, enabling students to recognize the importance of this science and its application in society.

EXAMPLES OF ACTIVITIES

Measuring the pH Value of Liquids

Students measure the pH value of various liquids (e.g., lemon juice, vinegar, water) using indicator paper, and analyze the results in the context of acid-base reactions.

Analysis of Product Composition

Students investigate the composition of different products (e.g., soaps, detergents) and discuss their applications.

Combustion Simulation

Using online simulations or practical demonstrations, students explore how various factors (temperature, oxygen amount) affect the rate and efficiency of combustion reactions.

Environmental Impact of Chemicals

Students research how industrial chemicals, such as pesticides or plastic materials, affect the environment and discuss possible solutions to reduce their negative impact.

METHODS AND STRATEGIES OF ACTIVE LEARNING IN CHEMISTRY TEACHING

By designing and incorporating active learning methods into the teaching process, not only is the memorization and understanding of information facilitated, but students' independence, responsibility, creativity, and motivation are significantly developed. Students are prepared for real-life situations where they will need to analyse, make decisions, collaborate, and apply what they have learned in various contexts. Moreover, active learning contributes to the formation of functional knowledge—knowledge that is not forgotten after testing but remains a lasting foundation for further learning and action.

In a time of rapid changes and an increasing need for flexible thinking and lifelong learning, this approach to teaching becomes essential. Although there are numerous possibilities for applying active learning methods in chemistry education, conducting experiments based on the theoretical concepts being taught at the moment is considered one of the most important, if not the most important, methods. Experiments enable students to make abstract chemical concepts visible, concrete, and understandable. In this way, students do not just listen about chemical reactions but investigate, observe, measure, compare results, and draw conclusions based on their own observations.

Experiments in Chemistry Teaching

Experiments encourage active student participation, as by designing and conducting all phases of an experiment, students become researchers. Effective integration of experiments into teaching requires setting clear objectives and selecting experiments that clearly illustrate theoretical concepts. Additionally, students should be allowed to

independently apply elements of the scientific method – from formulating hypotheses, through planning, performing the experiment, analyzing results, to drawing conclusions.

EXAMPLES OF ACTIVITIES

Neutralization reaction: Students can observe the reaction between baking soda and acetic acid (vinegar), noticing the fizzing and the release of carbon dioxide. This experiment helps reinforce their understanding of acids and bases.

Oxidation Reaction: Students can study the rusting process of iron when in contact with water or air. They can use different materials (such as aluminum or copper wire) to investigate how factors like humidity or temperature affect the rate of rusting and demonstrate that different metals behave differently under the same conditions.

Combustion of Organic Substances: At a basic level, students can observe the simple burning of paper, while at more advanced levels they explore the combustion of paraffin or fossil fuels, linking this reaction to ecological and environmental aspects.

This approach increases motivation, as students feel they are part of a real scientific process rather than passive observers. By conducting experiments, students develop a range of important competencies: attentiveness, precision, teamwork, responsibility, critical thinking, and problem-solving skills.

Experiments can be simple (e.g., observing a colour change in an acid-base reaction) or more complex (e.g., extracting metals from ores, ion identification). They can also be demonstrative, group-based, individual, or more recently, digital. Teachers often choose low-budget experiments, which ensures sustainability and helps develop competencies for working within the real conditions of the school environment.

Problem-Based Learning

Problem-based learning (PBL) is an active learning method in chemistry where the teacher assigns a real or imagined problem related to a real-life situation (e.g., how to clean polluted water or why metal corrodes), and students investigate, plan solutions, and present results in an interactive, team-oriented environment. This approach often requires an interdisciplinary perspective, considering the problem from multiple disciplinary angles.

Interesting examples of this method involve important social issues directly connected to aspects of chemistry, such as topics related to pollution and environmental conservation. Although there are examples of presenting the topic "Air Pollution and Acid Rain" to elementary school students, due to the required level of chemical competencies, this topic is more appropriate for high school students (e.g., 2nd or 3rd grade of gymnasium or vocational high school). It includes elements of inquiry-based learning, group work, connection to everyday life, and development of critical thinking.

EXAMPLES OF ACTIVITIES

Air Pollution and Acid Rain

This topic can be connected to key chemistry concepts such as oxides, acids, and neutralization reactions. However, through a problem-based approach, students can explore not only chemical reactions but also the social, ecological, and economic aspects of the issue.

Scenario for the topic ***"Air Pollution and Acid Rain"***:

1. Introduction to the problem (10 minutes): Students watch a video about the consequences of acid rain. The teacher asks questions about gases released during the combustion of fossil fuels and their impact on the environment.

2. Group work – research and analysis (40 minutes): Students are divided into groups to research the causes and consequences of pollution, linking chemical reactions with ecological issues. In the end, they propose measures to reduce pollution, such as lowering the nitrogen and sulfur content in fuels.

Debates in Chemistry Education

Organizing debates on chemistry-related topics that are also current social issues represents a form of active learning that is especially engaging in chemistry classes. Many social problems, both at the local and global level, are fundamentally rooted in chemistry as a science.

Some of these issues include the use of pesticides and food safety in general, plastics in everyday life, vaccine safety, the pros and cons of renewable energy sources, various natural resources, water, mining, and mineral raw materials, among others.













Such topics are often highly complex and require thorough preparation from teachers to ensure that debates remain grounded in arguments supported by verified scientific facts—especially considering that these topics are frequently the subject of conspiracy theories and pseudoscientific approaches. In addition to advanced chemical knowledge and scientific literacy, debates on current chemistry topics help students develop communication skills and connect learned knowledge to real-life situations.

Other Forms of Active Chemistry Teaching

In addition to the methods described above, here are several more selected approaches that can be successfully applied in chemistry teaching, along with concrete examples:

Creating Three-Dimensional Molecular Models

This method is especially effective in teaching organic chemistry, where students often struggle to understand the spatial structure of molecules. By using simple materials such as modeling clay, wooden sticks, wire, beads, or even recycled materials, students can create 3D models of methane, ethene, cycloalkanes, aromatic compounds, amino acids, and proteins. This activity helps students better grasp concepts such as molecular geometry, isomerism, conformations, and stereoisomerism. Commercial molecular modeling kits can also be used, particularly in vocational high schools and gymnasiums with more class hours, to help students make a deeper connection between theoretical knowledge and its visualization.

Steric number (hybridization and bond angle)	Lone pairs		
	0	1	2
2 (sp 180°)	 (Linear)		
3 (sp ² 120°)	 (Trigonal planar)	 (Bent)	
4 (sp ³ ~109.5°)	 (Tetrahedral)	 (Trigonal pyramidal)	 (Bent)
5 (dsp ³ 90°/120°)	 (Trigonal bipyramidal)	 (Seesaw)	 (T-shaped)
6 (d ² sp ³ 90°)	 (Octahedral)	 (Square pyramidal)	 (Square planar)



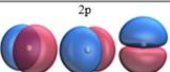

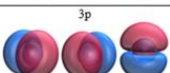
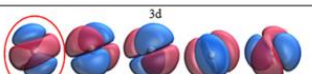
1s 	
2s 	2p 
3s 	3p 
	3d  (circle d _{xy})

Figure 3. Example of 3D models
(source: bmcrenotes.biomedcentral.com)

Educational Games and Quizzes

To review material and assess knowledge, teachers can design quizzes in various formats—digital (e.g., Kahoot, Quizizz), paper-based (card games with questions and answers), or competitive team games ("Who Wants to Be a Chemist?", "Chemical Millionaire"). In this approach, students learn through play while also developing quick thinking, teamwork, and a competitive spirit. Quizzes can be used as an introduction to a new lesson (to check prior knowledge), during the unit (for formative assessment), or at the end (for summative evaluation).

Project-Based Learning and Team Research Tasks

Certain chemistry topics are ideal for deeper exploration and teamwork. Students can work on mini-projects in small groups, investigating chemical aspects of everyday life: "Chemistry in Cosmetics", "Analysis of Soft Drink Ingredients", "Impact of Acid Rain on the Environment", "Microplastic Pollution", "The Chemistry of Medicines", and similar topics. Students gather information from various sources, conduct simple experiments or surveys, analyze findings, and present results through posters, PowerPoint presentations, videos, or bulletin boards. This method fosters inquiry-based learning, media and information literacy, and teamwork.

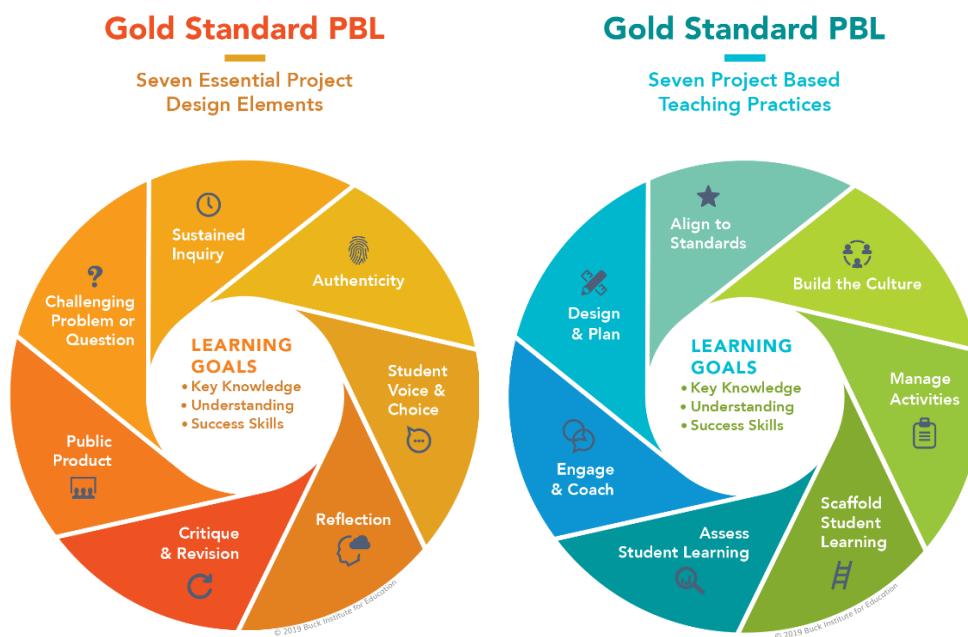


Figure 4. Project-based learning (source: pblworks.org)

Field Trips

Organizing visits to industrial plants, laboratories, pharmaceutical factories, university chemistry departments, or water treatment facilities allows students to experience chemistry as a real and useful science. Students can observe the application of processes such as distillation, filtration, neutralization, quality control, the use of modern analytical instruments, and environmental protection in real-world settings. These experiences strengthen motivation to learn, support career orientation, and bridge the gap between theory and practice.

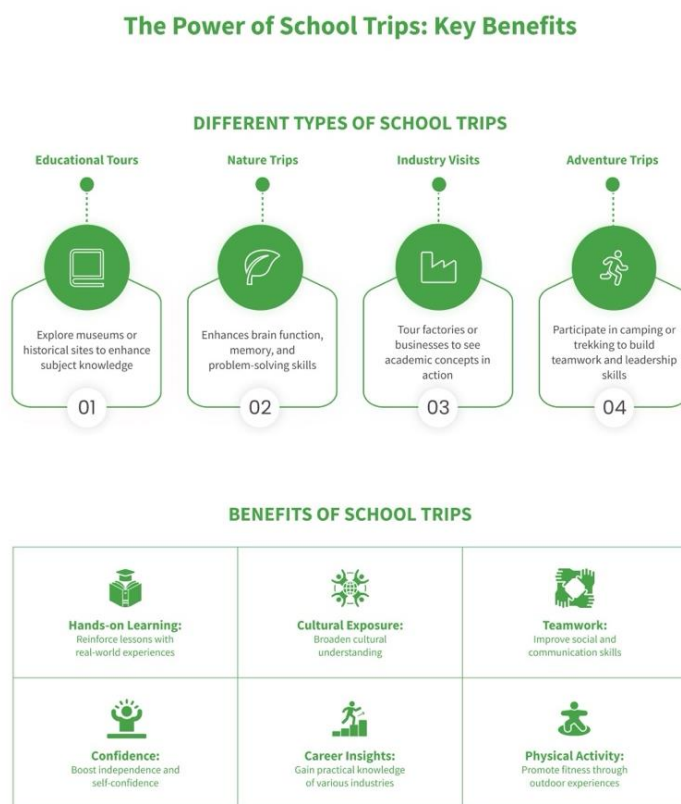


Figure 2. Benefits of field trips (source: varthana.com)

In general, incorporating active learning methods into chemistry teaching not only increases student engagement and interest but also leads to a deeper understanding of the material, the development of higher-order cognitive skills, and prepares students to tackle real-world problems. Chemistry teachers have a wide range of creative possibilities to turn their lessons into inspiring learning experiences.

ELEMENTS OF A MODERN CHEMISTRY CURRICULUM

STRUCTURE OF THE SUBJECT CURRICULUM

The chemistry curriculum serves as the foundation for planning, implementing, and evaluating instruction, while also providing guidance for teachers in achieving educational goals. It is not a mere collection of teaching content, but a carefully designed framework that directs students toward acquiring knowledge, developing skills, and forming attitudes in line with contemporary societal needs and scientific advancements.

In a modern educational approach, the chemistry curriculum is designed to support the development of functional and scientific literacy, with a particular emphasis on learning outcomes. These outcomes go beyond the simple reproduction of facts; they describe what students should be able to know, understand, apply, analyze, evaluate, and create within the context of chemical concepts and their practical applications.

Purpose and Objectives of the Subject

At the beginning of each curriculum, the purpose of the subject is defined, explaining why chemistry is studied within the education system and how it contributes to general education. Chemistry fosters the ability to understand the material world, think rationally, engage in experimental work, and make evidence-based decisions. Through learning chemistry, students develop awareness of the impact of science

and technology on everyday life, as well as a sense of responsibility toward the environment and society.

The objectives are designed to support the development of key competencies such as communication, problem-solving, digital literacy, collaboration, responsibility, and independent learning. In the context of chemistry, this means equipping students to analyze chemical processes, think critically about scientific claims, solve problems through logical reasoning, and apply acquired knowledge in real-life situations.

Thematic and Conceptual Framework

The curriculum is organized around thematic units and conceptual frameworks, enabling deeper understanding and integration of various areas of chemistry. Instead of listing topics linearly, modern programs integrate content through relevant, contextual, and often interdisciplinary themes. In this way, students develop the ability to recognize chemical principles in a variety of situations – from the kitchen, to health and ecology, to industry and energy.

Learning Outcomes – The Core of the Modern Curriculum

Learning outcomes are a key element of every subject curriculum. They are clear, measurable statements that define what a student should know, understand, and be able to do after a specific period of learning. The outcomes are based on different levels of cognitive development, according to the (revised) Bloom's taxonomy, and include:

- ***Knowledge and Understanding*** – the student recognizes basic chemical concepts (e.g., can define atom, molecule, element, compound);
- ***Application*** – the student uses knowledge in new situations

(e.g., calculates the amount of substance needed for a reaction);

- **Analysis** – the student connects causes and effects (e.g., analyses changes in an experiment and explains them);
- **Evaluation** – the student assesses information and draws conclusions (e.g., evaluates the impact of a chemical substance on the environment);
- **Creation** – the student designs new solutions or original experiments (e.g., develops an experiment to examine a neutralization reaction).

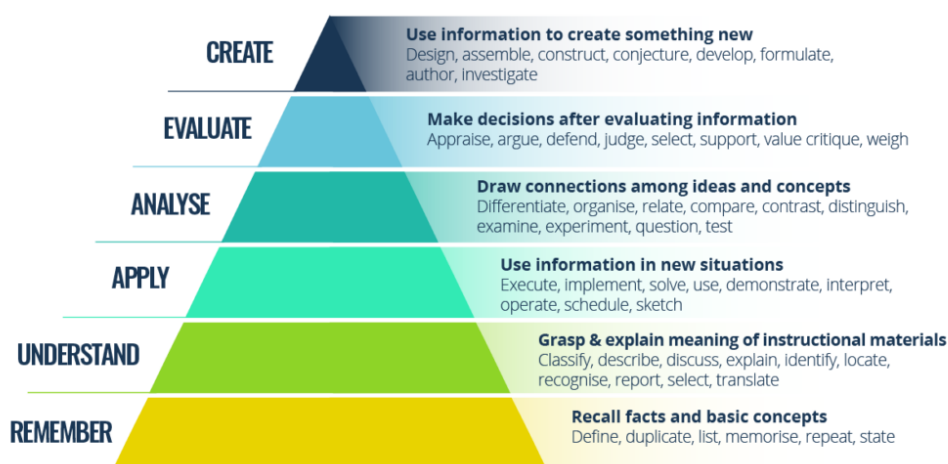


Figure 3. Bloom's taxonomy (www.growthengineering.co.uk)

While outcomes are often tied to specific content, they have a broader aim – the development of transferable competencies that can be applied to other fields and contexts. For example, a student who learns to analyse the results of a chemistry experiment also develops skills useful for solving real-world problems or making informed decisions about health or environmental issues.

In modern chemistry curricula, outcomes are frequently grouped into thematic domains, such as:

- Chemical Knowledge (understanding concepts),
- Experimental Skills (planning, conducting, interpreting),
- Health and Environment (applying knowledge in everyday life),
- Communication and Argumentation (expressing ideas in a scientifically grounded manner).

Methodological Support for Teachers

Subject curricula provide teachers with didactic-methodological guidance that supports the selection of teaching strategies without limiting their creativity and professional autonomy. These guidelines include recommendations for:

- Selecting active learning methods (experiments, debates, project tasks, problem-solving);
- Using digital tools (simulations, virtual experiments, video demonstrations);
- Organizing assessment (formative and summative evaluation, portfolios, presentations).

The purpose of these recommendations is to assist teachers in achieving the learning outcomes while also allowing them to reflect their own pedagogical style and the specific context in which they work.

Interdisciplinarity and Connection to the Real World

Chemistry curricula should highlight connections between chemistry and other subjects (e.g., biology, physics, geography, civic education) and with cross-cutting themes that transcend disciplinary boundaries,

such as climate change, energy, health, nutrition, and sustainable development. This helps students gain a broader perspective on the role of science and recognize the importance of chemical knowledge in the context of contemporary challenges.

Assessment and Evaluation of the Curriculum

A modern curriculum includes guidelines for assessing student achievement that are aligned with learning outcomes. Instead of relying solely on reproductive tasks, assessment should involve a variety of task types, including open-ended questions, practical assignments, reflections, and self-assessments.

In addition, the curriculum must provide for periodic evaluation of the curriculum itself, ensuring its relevance and effectiveness. This evaluation should be based on the analysis of achieved outcomes, feedback from teachers and students, and changes in science, society, and the labour market.

TOPICAL AREAS IN THE SUBJECT OF CHEMISTRY

The chemistry curriculum in secondary education in Bosnia and Herzegovina varies in duration and scope depending on the type of school and educational profile. From one-year courses in some vocational secondary schools to four-year programs in natural science-mathematics high schools, chemistry is a subject that offers great potential for the development of scientific literacy, critical thinking, and the ability to connect theory with the real world.

TRADITIONAL ORGANIZATION OF CONTENT

In most schools within our education system, chemistry instruction is still organized according to a linear model, where chemistry topics are addressed successively by grade level, largely following the historical development of chemical sciences:

- **First year:** General and Inorganic Chemistry. Topics include atomic structure, the periodic table, chemical bonds, and types of chemical reactions. In addition, students learn the properties of basic classes of inorganic compounds.
- **Second year:** Physical and Analytical Chemistry. The focus is on chemical kinetics, equilibrium, colligative properties of solutions, and the basics of chemical analysis.
- **Third year:** Organic Chemistry. Students are introduced to the structures and reactions of hydrocarbons, functional groups, and various organic substances.

- **Fourth year:** Chemistry of Natural Products and Biochemistry. Topics include basic biological molecules such as carbohydrates, fats, amino acids, proteins, enzymes, vitamins, and metabolic pathways.

This approach has certain advantages, such as systematic progression and gradual knowledge building. However, it often overlooks the functional application of chemistry and limits opportunities to connect with everyday contexts, other subjects, and contemporary challenges.

Although the linear approach allows for gradual acquisition of knowledge, in practice it often proves to be static and inflexible. Analysis of curricula and teaching practice points to the following:

- Insufficient connection between teaching topics and students' everyday lives.
- Mechanical inclusion of content without clearly defined learning outcomes.
- Lack of space for experimental work, interdisciplinarity, and the development of generic competencies.

These challenges become even more pronounced in two-year and three-year programs, where the curriculum is limited in scope, and students often do not gain a deeper understanding of chemical processes and their practical value.

MODERN APPROACHES TO ORGANIZING THEMATIC AREAS

In modern curricula worldwide, increasing emphasis is placed on the functional organization of knowledge and the development of competencies, with a focus on the student and learning outcomes. Two dominant approaches are:

Organization of Subject Content by Domains

This approach, applied in countries such as Finland, Estonia, Canada, Croatia, and many other educational systems, organizes chemistry instruction around thematic units with clearly defined purposes and learning outcomes. Instead of studying by scientific disciplines, content is structured to reflect:

- **Functionality of knowledge** – knowledge that students can apply;
- **Connection with the real world** – through topics that are familiar to students;
- **Knowledge spiral** – the same concepts are addressed at increasingly complex levels in different grades.

In practice, examples such as Finnish domains ("Structure of Matter," "Changes and Interactions," "Energy in Chemical Processes," "Chemistry in Everyday Life") clearly demonstrate how content is structured based on learning outcomes and real-life application.

Thematic or Problem-Based Organization

The thematic approach, commonly found in the Netherlands, Australia, and countries that follow international assessment frameworks, is based on inquiry questions that initiate the learning process. For example:

- "How do batteries work?"
- "What's the difference between soap and detergent?"
- "How does chemistry contribute to the fight against climate change?"

Such questions allow students to learn through investigation, discussion, and hands-on experiments, fostering the development of critical thinking and creativity.

Integrated Science Teaching

In the USA, the UK, and Norway, it is increasingly common to study chemistry within the broader subject of "Science," together with biology and physics. The advantages of this approach include:

- Learning through projects and themes that involve multiple disciplines;
- Developing interdisciplinary connections and functional knowledge;
- Better preparation of students to solve complex problems in today's world.

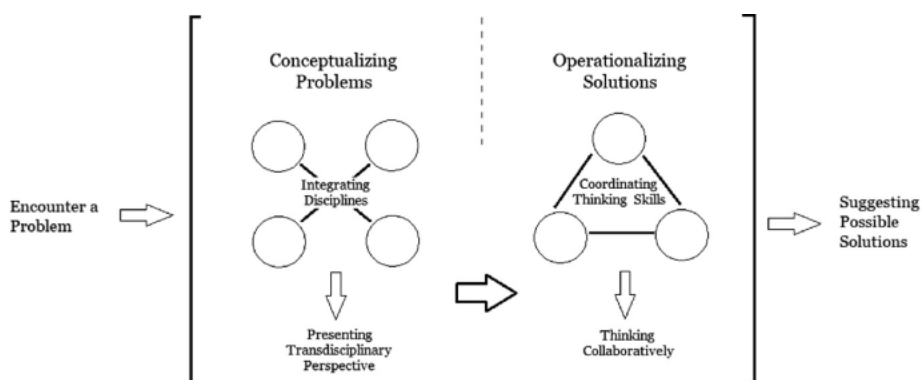


Figure 4. Education of integrated science (source: Education of Integrated Science: Discussions on Importance and Teaching Approaches, link.springer.com)

LEARNING OUTCOMES AS THE STARTING POINT FOR ORGANIZING CONTENT

Regardless of the model, modern organization of subject areas cannot be envisioned without clearly defined learning outcomes. Learning outcomes are concrete and measurable statements that describe:

- What the student should **know** (knowledge),
- What the student should **understand** (comprehension),
- What the student should **be able to do** (skills and competencies).

Thematic areas in a modern curriculum are formulated to support the achievement of learning outcomes, and content is selected as a means to achieve them. For example:

- In the area **“Chemistry and Health,”** an outcome may be: *“The student analyzes the role of different chemical substances in the human body and draws conclusions about their impact on health.”*
- In the area **“Matter and Changes,”** an outcome may be: *“The student predicts the course and consequences of chemical reactions based on knowledge of chemical laws.”*

Learning outcomes formulated in this way facilitate lesson planning, assessment, and differentiation of instruction based on context, student interests, and available resources.

Recommendations for Improving the Organization of Thematic Areas

To modernize chemistry teaching, the following activities and interventions within subject programs are recommended:

- Gradual integration of domain-based and problem-based instruction, starting from thematic units within the existing structure;
- Clear linking of areas with learning outcomes and competencies – each area should include a justification for its inclusion;
- Introduction of flexible modules and elective topics – such as *“Chemistry and Energy,” “Food Chemistry,” “Chemistry and Society”*;
- Use of interdisciplinary projects and scenarios – where chemistry is connected with biology, geography, physics, ICT, and civic education;
- Continuous teacher education – to ensure proper interpretation and implementation of modern approaches.

LEARNING OUTCOMES AND COMPETENCIES

Modern educational systems are increasingly moving away from traditional approaches and focusing on learning outcomes and the development of competencies in students. In this process, new terms are introduced into professional and general educational terminology, often leading to confusion or interchange of terms such as "competence," "learning outcome," "skill," and "ability."

Although these terms are frequently used as synonyms, there are important differences that must be understood in order to successfully apply them in lesson planning, implementation, and evaluation.

COMPETENCIES

Competencies represent a combination of knowledge, skills, attitudes, and abilities that enable a person to act effectively, responsibly, and independently in various contexts—in learning, work, and everyday life. According to the European Commission's definition, competence is: *"The proven ability to use knowledge, skills, and personal, social and/or methodological abilities in work or study situations and in professional and personal development."*

Thus, competencies include not only what a person knows but also their ability to apply that knowledge and those skills in real-life circumstances. They are broad educational goals that teaching should develop and support.

LEARNING OUTCOMES

Learning outcomes are concrete, clearly formulated statements describing what a student should know, understand, and be able to do upon completion of a particular educational process. Unlike competencies, which represent the ultimate result, learning outcomes are measurable steps leading to the development of competencies.

For example, in chemistry teaching:

- **Competency:** Developed scientific literacy and the ability to apply chemical concepts in everyday life.
- **Learning Outcome:** The student explains the properties and applications of soaps and detergents based on the chemical structure of their molecules.

In this way, learning outcomes can be considered tools for achieving competencies. Well-formulated learning outcomes help teachers clearly define lesson objectives, plan activities, and develop assessment strategies, while enabling students to understand what is expected of them.

KEY COMPETENCES FOR LIFELONG LEARNING

The concept of key competencies was developed in response to the needs of the knowledge society, rapid technological change, and globalization of the labour market. The European Union adopted the Key Competences Framework in 2006, which was revised in 2018 to better address challenges related to digitalization, sustainable development, and social inclusion.

Key competencies for lifelong learning represent a set of knowledge, skills, and attitudes necessary for every individual for:

- personal development,
- employment,
- active citizenship, and
- social inclusion.

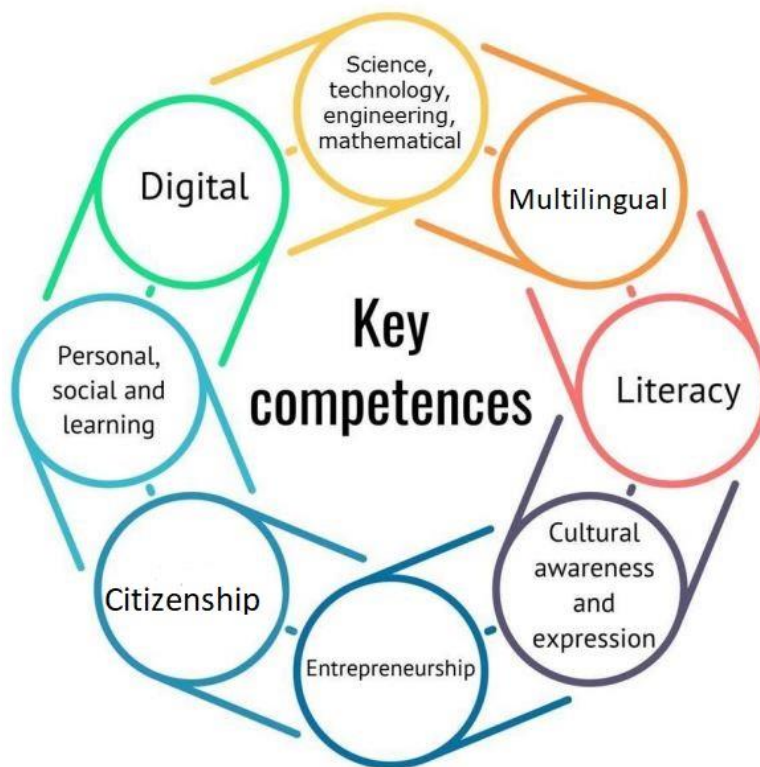


Figure 5. Key competences (source: kivinen.wordpress.com)

According to the Recommendation on Key Competences for Lifelong Learning (2006, revised 2018), eight key competencies have been identified:

1. Literacy – language and communication skills in the mother tongue
2. Foreign language communication
3. Mathematical, scientific, and technological competence
4. Digital competence
5. Personal and social development, learning to learn
6. Civic competence
7. Entrepreneurial Competence
8. Cultural Awareness and Expression

Key competencies form the foundation for all school subjects, including chemistry. They are not developed in isolation but through integrated curricular content and student-centered pedagogical approaches.

GENERIC COMPETENCIES

In the literature, terms such as generic competencies, general competencies, transversal competencies, or transferable skills are often used. These encompass skills and abilities that are not specific to a particular field of knowledge but are important across all contexts of education, work, and life.

Examples of generic competencies include:

- Oral and written communication
- Critical thinking
- Problem-solving
- Teamwork and collaboration

- Time management
- Independent learning
- Digital literacy
- Ethical and responsible behaviour

Generic competencies are an important part of modern curricula because they help students adapt to change, communicate effectively, and make responsible and informed decisions. They are developed across all subjects, projects, extracurricular activities, and interdisciplinary content.

Table 2. Terminological Differences Between Various Types of Competencies

Term	Meaning
Key Competencies	Basic competencies needed for life, work, and lifelong learning
Competencies for Lifelong Learning	A broader concept that includes the ability to learn continuously throughout life
Generic Competencies	General skills that can be applied in various contexts

CHEMISTRY IN EVERYDAY LIFE AND PRACTICE

One of the main goals of modern chemistry education is for students to acquire knowledge and skills they can apply in real-life situations. To move chemistry beyond the abstract realm of formulas and laboratories, it is essential to connect it with students' experiences, everyday habits, and surroundings. For this reason, special attention should be given to areas that enable the understanding of chemical principles through examples from daily life.



This chapter highlights the importance of integrating chemistry into contexts familiar to students—household, nutrition, health, hygiene, and the environment. Such an approach not only makes teaching more

engaging and relevant but also contributes to the development of scientific literacy, critical thinking, and a responsible attitude toward nature and personal health.

For teachers, this is an opportunity to use topics that students can easily recognize, analyse, and discuss, and to encourage deeper understanding of the role of chemistry in society through practical activities and projects. Connecting subject content with everyday practices supports the development of functional knowledge and strengthens the competencies needed for lifelong learning.

CHEMISTRY IN THE HOUSEHOLD

The application of chemistry in everyday life can be highly engaging and motivating for students, especially when connected to household examples. Teachers can use this area to explain important chemical concepts and principles through familiar, everyday situations, thereby placing theoretical knowledge into a context that is understandable and relatable for students.

Composition and Function of Cleaning Agents

The introduction to this lesson unit can begin with an exploration of the composition of detergents and soaps, products that are part of every family's daily routine. The key components of these products are surfactants, chemical compounds that reduce the surface tension of water and enable the effective removal of dirt and grease.

Teachers can:

- explain the structure of surfactant molecules (hydrophobic and hydrophilic parts),
- visually demonstrate the mechanism of dirt removal,

- analyze labels of various products and compare their compositions.

This topic provides a solid foundation for combining theoretical knowledge with practical skills through label analysis tasks, discussions about usage, and the environmental impact of cleaning agents.

Chemical Reactions in Washing and Cleaning

Washing does not only remove physical dirt; it also involves actual chemical changes. Soaps and detergents emulsify fats, allowing them to be washed away with water.

The lesson can cover:

- the principle of fat emulsification and the role of soap in this process,
- simple experiments (e.g., mixing oil, water, and detergent) to observe the effect of soap,
- the use of molecular model visualizations and animations to help students understand the chemical basis of cleaning.

These topics can be implemented through experimental work, group discussions, or research assignments, promoting active learning and the development of scientific literacy.

Chemicals and Products in the Household

In addition to soaps and detergents, the lesson can also cover other chemical products commonly found in households: disinfectants, fabric softeners, polishes, and so on.

Teachers can guide students to:

- research the active substances contained in these products and

their functions,

- distinguish between types of chemicals based on their effects (e.g., antibacterial, anti-limescale, water softeners),
- understand the differences between acidic, basic, and neutral cleaning agents.

A practical task could involve comparing various cleaning products and classifying them according to their chemical properties, helping students develop evaluation skills and analytical competence.

CHEMISTRY AND HEALTH

One of the most important and most relatable applications of chemistry in everyday life is its connection to health. By exploring the chemical composition of medicines, bodily processes, and food ingredients, students develop an understanding of how chemistry directly affects human health and well-being. Chemistry education can significantly contribute to raising awareness about responsible attitudes toward personal health, as well as the importance of scientific knowledge in making health-related and lifestyle decisions.

Chemical Composition of Medicines and Their Effect on the Body

Medicines are compounds whose chemical structure allows them to act specifically on certain processes within the body. Teachers can explain to students the basic principles of how medicines work—for example, how analgesics block pain signals, how antihistamines reduce allergic reactions, or how antibiotics destroy bacteria. Concepts such as active substances, excipients, and pharmacodynamics can be introduced through simple examples and illustrations.

In addition, the importance of proper medication use can be discussed, along with the risks of self-medication or misuse.



Chemistry in Vaccines, Antibiotics, and Other Therapies

Students often hear about vaccines and antibiotics but rarely understand their chemical foundations. Teachers can explain that vaccines contain antigens that stimulate the immune response without causing disease, and that many vaccines are the result of sophisticated biochemical processes.

The lesson can include explanations of different types of vaccines (e.g., mRNA vaccines), as well as the basic principles of how antibiotics work, with clarification as to why they are not used against viruses. A discussion on antibiotic resistance can encourage critical thinking and responsible behaviour.

Chemistry in the Food Industry: Additives, Preservatives, and Flavors

Many food products that students consume daily contain various chemical additives. This topic allows teachers to introduce a discussion about food additives—preservatives, colorants, thickeners, emulsifiers, and artificial flavors. Students can analyze the labels of products brought from their own homes, thereby linking the lesson to real-life experiences. In this context, it is important to foster scientific literacy—understanding that the presence of a chemical does not necessarily imply something harmful, and that dosage and context are key factors in determining benefit or risk.

Chemical Processes in the Human Body – Digestion, Metabolism, Respiration

Basic biochemical processes such as food digestion, cellular respiration, oxygen transport, and glucose breakdown are excellent examples of how chemistry functions within our bodies. Students can learn how enzymes accelerate reactions, how nutrients are converted into energy, and how the balance of substances (e.g., pH levels, electrolyte balance) maintains bodily health. This knowledge allows students to gain a deeper understanding of how their bodies function, thereby fostering a responsible attitude toward their own health.

CHEMISTRY AND ENVIRONMENTAL PROTECTION

Chemistry plays a fundamental role in understanding, monitoring, and addressing environmental protection issues. A modern approach to chemistry education should develop students' awareness of the connection between chemical processes and nature conservation, and encourage a responsible and sustainable attitude toward the use of

natural resources. This topic enables an interdisciplinary approach by linking chemistry with ecology, biology, geography, and social sciences.

Pollution of Water, Air and Soil

Teachers can explain to students how various chemical compounds resulting from human activity enter the natural environment and cause pollution. For example, nitrates and phosphates from fertilizers enter water bodies and cause eutrophication; burning fossil fuels releases gases such as carbon dioxide, carbon monoxide, sulphur dioxide, and nitrogen oxides into the atmosphere; industrial waste contaminates soil with heavy metals.

Students can investigate examples from their local community and analyse the sources and consequences of pollution, thus creating a direct connection between chemistry and everyday life.

Chemical Reactions in Nature – Acid Rain, Greenhouse Effect, Climate Change

Through this topic, students can understand how chemical reactions contribute to global ecological challenges. For example:

Acid rain forms when sulphur dioxide (SO_2) and nitrogen oxides (NO_x) react with water in the atmosphere, creating acids (H_2SO_4 and HNO_3) that fall to the ground, damaging plants, buildings, and watercourses.

The greenhouse effect is explained by the presence of gases such as CO_2 that absorb heat and contribute to warming the atmosphere.

Climate change is a consequence of increased greenhouse gas concentrations, resulting in altered precipitation patterns, rising sea levels, and reduced biodiversity.

Teachers can use models and simulations to help students visualize

these processes, as well as analyse current data from scientific sources.

Chemical Processes in Recycling and Resource Recovery

Recycling has recently been recognized as one of the most important processes for conserving resources and reducing pollution, with chemistry playing a key role in the separation, processing, and reuse of materials. Students can explore how metals are extracted from waste, how plastics are sorted and chemically recycled, and how biochemistry is used to decompose organic materials. New technologies can also be introduced, such as chemical catalysts for plastic degradation or methods for extracting valuable elements from electronic waste.

The Role of Chemistry in Sustainability and the Application of Environmentally Friendly Technologies

The chemistry of the future is focused on sustainability. Teachers can introduce the concept of green chemistry—a strategy aimed at minimizing the use and generation of hazardous substances in chemical processes. Through this topic, students can learn about:

- biodegradable materials,
- alternative energy sources (e.g., fuel cells, solar energy),
- energy-saving catalytic processes,
- the development of harmless pesticides and detergents.

This area encourages students to think as responsible citizens and future professionals who can contribute with their knowledge to solving ecological problems. Understanding the role of chemistry in environmental protection strengthens their ability to think critically and apply scientific knowledge in everyday life and informed decision-making.

CHEMISTRY IN INDUSTRY AND TECHNOLOGY

At the core of many industrial and technological processes shaping modern life are new materials and technologies based on chemical sciences. Students should gain insight into how chemistry knowledge is applied on a large scale for the production of various materials and devices present in everyday life. This topic fosters an understanding of the practical application of theoretical knowledge, as well as awareness of the industry's impact on the environment and the need for sustainable development.

Industrial Chemical Processes

Teachers can present key industrial processes relying on chemistry, explaining their basic principles and significance:

- Oil refining involves processes such as distillation and cracking, which convert crude oil into useful products: gasoline, diesel, heating oil, plastics.
- Plastic production uses polymerization chemical reactions—students can analyse the differences between thermoplastics and thermosetting plastics, as well as issues related to their degradation and recycling.
- Glass and rubber production can be explained through the transformation of raw materials like silicon dioxide and natural rubber, giving students insight into changes in material structure and properties.

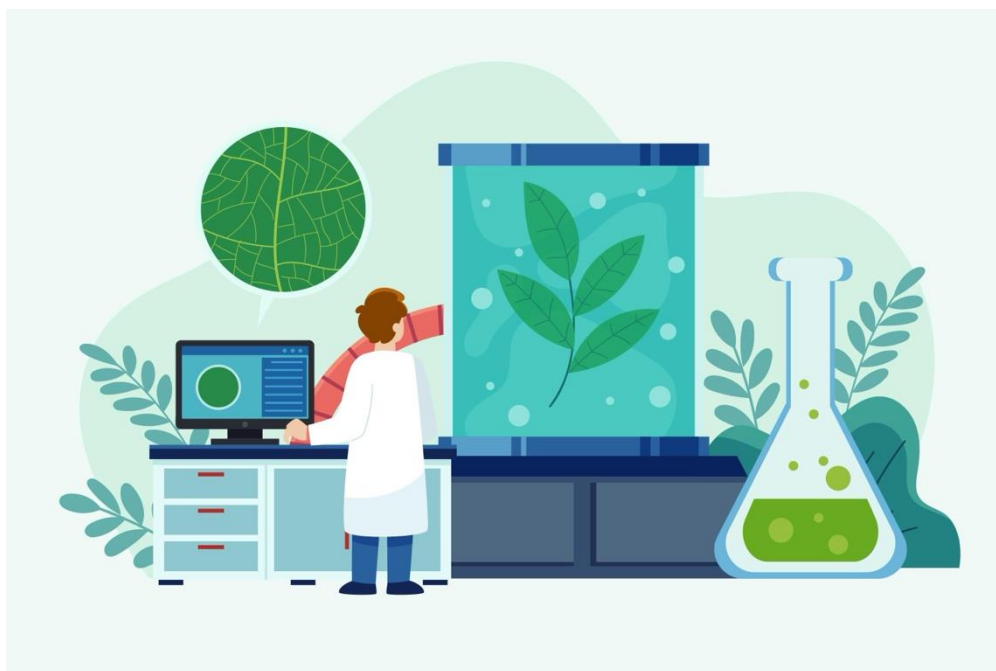
Through examples from local industry or virtual plant tours, students can gain a more concrete understanding of the application of chemistry in manufacturing.

Chemistry in Modern Technologies

Modern technology is unimaginable without chemistry. Teachers can cover the following examples:

- Batteries and their chemical basis—lithium-ion batteries, oxidation and reduction processes, energy storage and release.
- Electronics, where chemistry is used in manufacturing semiconductors, chips, and LEDs.
- Nanotechnology, a field where materials are manipulated at the atomic and molecular level—students can learn how nanomaterials are used in medicine, textiles, cosmetics, and protective coatings.

These topics can be connected with the STEM approach in teaching, developing students' technical and digital literacy.



Green Chemical Processes and Sustainable Industry

Learning about industrial chemistry should also include critical consideration of the environmental impact of these processes. Green chemistry represents a set of principles aiming to develop processes that are efficient, less energy-consuming, and less harmful to the environment. Students can be introduced to:

- alternatives to toxic solvents,
- biodegradable materials,
- processes with reduced greenhouse gas emissions,
- circular economy and raw material reuse.

Through discussions and project tasks, teachers can encourage students to think about how science can contribute to creating a more sustainable society.

BASICS OF USING ARTIFICIAL INTELLIGENCE IN CHEMISTRY EDUCATION

Although artificial intelligence (AI) is currently the subject of global debate and is considered controversial by many, its application in teaching and learning certainly brings numerous opportunities worth exploring. Certain elements—or tools—of artificial intelligence already have their place in modern education, offering opportunities for personalized learning, improved teaching methods, and more efficient information processing. In the context of chemistry education, AI serves as a tool that significantly modernizes the field by pushing the boundaries of traditional teaching and opening up space for interactive, more creative, and deeper knowledge acquisition.



However, integrating AI into the classroom requires a thoughtful approach, both technical and pedagogical preparedness of teachers, as well as a critical reflection on the ethical and didactic aspects of using such tools. That is precisely why we aimed to shape this chapter by also using the possibilities offered by artificial intelligence—including the

very text you are reading. In its creation, the generative language model ChatGPT was used, giving the author an opportunity to directly examine the potential of this form of collaboration.

The experience of writing with the help of AI has shown that ChatGPT is impressive in its speed of data processing, ability to communicate at a high academic level, and contextual expression aligned with educational settings. We believe that both students and teachers can learn a great deal from such interaction—not only about content but also about clarity, style, and communication culture. At the same time, it became clear that the data AI provides often requires additional verification, interpretation, and adaptation to the pedagogical context. The tone, style, and way of addressing topics cannot replace the teacher's authorship—on the contrary, it is essential in order for the final result to have meaning and value in education.

As a university professor with many years of experience in education, the author saw this collaboration as the beginning of an exciting new chapter in her own learning journey. The use of AI in the creation of this section of the handbook represents the first step in the ChemTeach project, within which further development of educational resources will continue. A more detailed manual, *Multimedia in Chemistry Education*, is also planned, where the use of ChatGPT and related tools will be further elaborated. According to the author's own testimony, this experience clearly expands horizons regarding the possibilities AI offers, while also reaffirming the crucial role of the teacher as both facilitator and author in the educational process.

We believe that by creating clear guidelines and pedagogically focused handbooks, we can make it easier to use AI as a powerful tool for educating future generations.

ARTIFICIAL INTELLIGENCE AND ITS POTENTIAL IN CHEMISTRY EDUCATION

The introduction of artificial intelligence (AI) in education brings changes that chemistry teachers cannot ignore. AI offers new tools that facilitate lesson planning, personalize learning, and visualize abstract content. Although still relatively new in educational practice, AI can become a valuable ally in the classroom - if used meaningfully and with clear objectives.

Chemistry teachers can use AI in all stages of the teaching process:

- during lesson preparation (e.g., creating questions and materials),
- during lesson delivery (visualizations, simulations)
- in evaluation (response analysis, formative assessment).

Useful tools include ChatGPT and similar language models for quickly generating content, definitions, tasks, explanations, and synthesizing scientific texts. *Labster* and other simulation platforms allow the performance of virtual experiments in schools without laboratory conditions. *CenturyTech* and other personalized learning systems can be used to support differentiated instruction.

There are also automatic analysis systems that provide insight into common student errors and can recommend corrective actions. A detailed overview of AI tools with simple examples of use is provided in **Table 3**.

Table 3. Examples of Using Artificial Intelligence Tools in Chemistry Teaching

Tool / Technology	AI Function	Examples of Application in Chemistry Teaching
ChatGPT	Text, answer, question generation, content analysis	Preparation of questions for knowledge checks, creation of problem-solving tasks, simplification of concepts
Labster	Simulation of experiments in a virtual environment	Performing chemistry experiments in schools without laboratories, visualization of processes
ScribeSense	Automated grading and analysis of handwritten work	Quick evaluation of homework, error detection, and identification of student needs
CenturyTech	Personalized learning and recommendations	Adapting teaching content according to students' knowledge level and interests
Consensus	Searching scientific literature with summaries of key information	Teachers and students can quickly obtain reliable sources and use them in research papers
Canva AI, DALL-E	Generation of educational visuals and illustrations	Creation of posters, infographics, and visual representations of chemical processes
Turnitin, GPTZero	Detection of plagiarism and AI-generated content	Checking the authenticity of student work and monitoring the ethical use of AI
Google Bard / Copilot	Assistance in planning, writing, and organizing content	Support for teachers in creating teaching materials, lesson plans, and evaluation forms

EXAMPLES OF AI APPLICATION IN CHEMISTRY TEACHING PRACTICE

The use of artificial intelligence (AI) in the teaching practice of chemistry is no longer a matter of the future – it is increasingly becoming an everyday tool that facilitates teachers' work and enriches students' learning. This section presents several concrete examples of how AI can support various aspects of the teaching process, from lesson preparation and content creation to differentiated instruction and formative assessment. Each example highlights not only the technical functionality of the tool but also the pedagogical context in which it is used, since it is the teacher who shapes a meaningful and responsible approach to the use of new technologies. These examples can serve as inspiration, but also as a starting point for reflecting on the further integration of AI into modern chemistry education.

EXAMPLES OF ACTIVITIES

Example 1: Preparing knowledge-check questions

The teacher uses a generative model to request a series of multiple-choice, fill-in-the-blank, and problem-solving tasks based on a topic, for example, "Acids and Bases." The teacher then revises the generated suggestions and adapts them to the lesson objectives.

Pedagogical aspect: AI speeds up the preparation process, but the teacher remains responsible for the quality and validity of the questions.

Example 2: Visualization of molecules and reactions

While covering molecular structure, the teacher uses tools supported by AI to generate 3D molecular models. Students can rotate the molecules, modify electron configurations, and observe spatial relationships.

Pedagogical aspect: Students develop spatial orientation and gain a better understanding of concepts that are difficult to illustrate using traditional teaching tools.

Example 3: Differentiated instruction

AI helps the teacher analyze the results of previous tests and create, for instance, three versions of tasks on the same topic tailored to the students' abilities and interests.

Pedagogical aspect: AI facilitates individualized learning, thereby increasing student engagement and motivation.

Example 4: Formative assessment

During a lesson unit, for example, "Redox Reactions," the teacher uses a system that automatically analyzes students' short answers and groups them according to the frequency of misconceptions. This helps the teacher plan future lessons.

Pedagogical aspect: The teacher receives timely feedback and can adjust the instructional approach accordingly.

Example 5: Using AI to create materials

Teachers can use AI to: develop worksheets, simplify scientific articles for student research projects, generate quizzes, and create animations that illustrate chemical changes.

ADVANTAGES AND DISADVANTAGES OF APPLYING AI IN CHEMISTRY TEACHING

The application of artificial intelligence in chemistry teaching brings numerous advantages, but also challenges that accompany it. While technology enables personalized learning, more efficient lesson planning, and increased student motivation, there are important issues related to ethics, dependence on technology, and access to digital resources. This section analyses the key advantages and disadvantages of AI application in the educational process, aiming to help teachers better understand the possibilities and limitations of this technology.

Advantages of AI Application in Chemistry Teaching

The use of artificial intelligence in education offers many benefits for both students and teachers, which can improve the quality of teaching and make it more efficient and accessible. For better lesson organization, some of the most important advantages that teachers should keep in mind for more effective lesson planning include:

- **Individualization and personalization of learning.** With AI,

students can learn at their own pace, allowing better adaptation. AI-based tools can recognize individual student needs and provide personalized tasks and support in real time, significantly increasing the efficiency of the learning process.

- **More efficient lesson planning and evaluation.** Teachers have more time for creative and research activities because AI tools take over routine tasks such as assessing student work or automating administrative duties. This kind of support allows teachers to focus on key aspects of teaching and develop innovative learning approaches.
- **Increased student motivation.** Interactive AI-based tools and simulations make lessons more dynamic and engaging. The use of gamification, virtual laboratories, and other tools that allow practical application of theoretical knowledge can significantly increase student involvement and motivation.
- **Development of digital competencies.** Through the use of AI, students acquire important digital skills and learn how to use advanced technologies responsibly. These skills are essential for their future professional lives, especially in fast-developing industries that require a high level of technological literacy.

Disadvantages and Challenges of AI Application in Chemistry Teaching

Despite the advantages, the application of AI in education brings certain challenges and limitations that require careful consideration (considering DigiComp 3.0):

- **Issues of ethics and academic integrity.** Easily accessible tools for automatic answer generation can lead to misuse, where students use AI as a substitute for their own thinking and

creativity. This can undermine academic integrity and reduce the development of critical thinking skills in students.

- **Dependence on technology.** There is a risk of over-reliance on technology, which can lead to diminished critical thinking and independent work abilities. If teachers and students rely too much on automated systems, basic skills such as data analysis and problem-solving may decline.
- **Unequal access to digital resources.** Inequality in access to the internet and digital devices can worsen educational disparities among students. Students from poorer or rural areas may be deprived of the same educational opportunities offered by AI, deepening existing gaps.
- **Required digital literacy of teachers.** For teachers to effectively use AI tools, continuous education and support are essential. Teachers need to develop digital competencies and the ability to integrate new technologies into the teaching process, which can be challenging for those less familiar with modern technological tools.

RECOMMENDATIONS FOR CHEMISTRY TEACHERS ON A RESPONSIBLE APPROACH TO ARTIFICIAL INTELLIGENCE

The role of the teacher in the digital age does not diminish – it transforms. Artificial intelligence can be a powerful tool in chemistry teaching, but only if the teacher guides, supervises, and uses it with pedagogical purpose. In the hands of an educated and motivated teacher, AI does not pose a threat, but rather offers an opportunity to

enhance teaching, stimulate curiosity, and empower students for a rapidly changing world. For AI to be truly beneficial, the teacher must position themselves as a critical user and facilitator. Some of the most important recommendations include:

- Developing digital competence through continuous professional development. It is recommended to become familiar with the basic principles of generative models and systems for processing educational data.
- Constantly reviewing the content generated by AI. Language models may provide superficial, inaccurate, or non-pedagogical suggestions. The teacher must be ready to intervene and correct incomplete or incorrect information.
- Teaching about responsible use of AI. The teacher has the obligation to consistently explain the difference between using AI as a learning support and its misuse for cheating.
- The human component of education is paramount. Technology must serve education, not the other way around. All tools and assistance used aim to achieve the set learning outcomes and the acquisition of competencies by students.
- Combining various tools with other active learning methods. AI is best used in combination with other forms of learning such as experiments, debates, problem-based learning, projects, and similar activities.

Artificial intelligence in chemistry teaching opens space for innovation, better organization of lessons, and deeper understanding of complex concepts. However, its successful integration in the school context requires a thoughtful pedagogical approach, ongoing teacher development, and clear ethical guidelines for use. Artificial intelligence

is not a threat to the teacher's role – on the contrary, it is an ally in achieving educational goals, provided it is used responsibly, critically, and in the service of developing students' knowledge and competencies.

