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FEATURES OF DEVELOPING THE TEACHING MANUAL FOR THE COURSE «OXIDIZING AGENTS IN PHARMACY: FROM CHEMICAL ANALYSIS TO CLINICAL APPLICATION» FOR FUTURE PHARMACISTS AND BIOTECHNOLOGISTS WITHIN THE ERASMUS+ UKRAINEDIGITRANS PROJECT

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Abstract

Introduction. To address the shortage of materials integrating chemical theory, clinical practice, and digital tools, this study investigates the development of a manuscript for the course «Oxidizing Agents in Pharmacy» and its potential to enhance pharmacy and biotechnology students' competencies via AI and simulation technologies.
Aim. To investigate the organizational, methodological, and digital features of developing this educational manuscript and evaluate its impact on professional competencies, analytical skills, and clinical thinking.
Materials and methods. The manuscript was developed based on a systematic analysis of the literature (2020-2026), alignment with the State Pharmacopoeia of Ukraine, and a review of pharmacy curricula. A modular, competency-oriented structure comprising 5 learning outcomes aligned with Bloom's Taxonomy was developed. The course (1 ECTS, 30 hours, hybrid format) targets second- and third-year students majoring in Pharmacy, Biotechnology, and Bioengineering. Digital tools were integrated into the course architecture, with feedback collected via surveys and the LMS. Data processing included a descriptive analysis of content alignment.
Results. The developed manuscript integrates the physicochemical properties and mechanisms of action of oxidizing agents (peroxides, halogens, manganese salts), oxidimetric analysis (permanganatometry, iodometry, cerimetry), pharmaceutical compatibility, and clinical aspects. Special emphasis is placed on digital simulations and virtual laboratories for safe titration, AI for predictive modelling of incompatibilities, and student-driven development of «Digital Oxidizer Case Studies». The course comprises theoretical modules, case studies, and a final capstone project (accounting for 70% of the grade). It leverages Canva, Padlet, Moodle, generative AI, and titration simulators to support practice-oriented learning.
Conclusions. The modern educational manuscript effectively modernizes pharmaceutical education by bridging chemical analysis with clinical practice. The integration of hybrid learning, simulations, and AI fosters critical thinking, professional ethics, chemical safety, and readiness for quality control and extemporaneous compounding tasks. Continuous curriculum improvement guided by student performance data is recommended.

Keywords: **educational manuscript, pharmacy education, biotechnology, oxidizing agents, oxidimetric analysis, digital pedagogy, simulation technologies, artificial intelligence, individualized learning**

INTRODUCTION

The modernization of medical and pharmaceutical education in Ukraine is aimed at strengthening practical and digital components, fostering competency-based learning, and promoting interdisciplinary integration to meet the needs of the modern pharmaceutical industry and healthcare sector. In this context, oxidizing agents play a pivotal role as antiseptic and disinfectant agents, serving as critical reagents in pharmaceutical analysis

(particularly oxidimetric methods), while also directly influencing drug stability and participating in oxidative stress pathways.

Traditional curricula often address these topics fragmentarily within the boundaries of general and inorganic chemistry, analytical chemistry, and clinical pharmacy. The development of a specialized educational manuscript for the course 'Oxidizing Agents in Pharmacy: From Chemical Analysis to Clinical Application'—funded within the framework of the ERASMUS+ UkraineDigiTrans grant project – enables a holistic, structured, and practice-oriented approach. This alignment supports the University's Development Strategy and fosters the integration of innovative digital tools, virtual laboratories, and artificial intelligence into the training of future pharmacy and biotechnology professionals.

This article analyzes the key features of developing such an educational manuscript, focusing on content structuring, methodological approaches, the integration of digital technologies, and the expected impact on the professional competencies of higher education students, particularly those majoring in «Pharmacy» and «Biotechnology and Bioengineering».

AIM

To investigate the organizational, methodological, and technological features of developing an educational manuscript for the course «Oxidizing Agents in Pharmacy: From Chemical Analysis to Clinical Application» and to evaluate its potential benefits, implementation challenges, and impact on the development of professional competencies, analytical skills, clinical thinking, and readiness for pharmaceutical and biotechnological practice.

MATERIALS AND METHODS

The educational manuscript was developed based on a systematic analysis of scientific literature concerning oxidizing agents, pharmaceutical analysis, and digital pedagogy [1-5], ensuring alignment with the State Pharmacopoeia of Ukraine (SPU) [6], a review of the higher education standards for the Master's degree in Pharmacy [7] and Biotechnology and Bioengineering [8, 9], and expert consultations. A modular, competency-oriented structure was designed, featuring five learning outcomes aligned with the levels of Bloom's Taxonomy. The course workload is equivalent to 1 ECTS credit (30 hours), delivered in a hybrid format, targeting second- and third-year undergraduate students majoring in Pharmacy and Biotechnology and Bioengineering. Pilot elements and digital tools were integrated into the course architecture, with plans to collect feedback via surveys and the Learning Management System (LMS). Data processing includes a descriptive analysis of content alignment and assessment tools.

The core components of the developed curriculum include: (1) the physicochemical properties and molecular mechanisms of action of the main groups of oxidizing agents; (2) the methodology of oxidimetric analysis, focusing on permanganatometry, iodometry, and cerimetry; (3) the pharmaceutical compatibility of oxidizing agents and risk forecasting using digital databases; and (4) the integration of virtual laboratories, simulations, and generative artificial intelligence.

Instructional methods encompass interactive lectures, the flipped classroom model, the case study method, project-based learning, demonstrations, and group discussions. Student assessment involves formative evaluation tools (such as quizzes, exit slips, and virtual laboratory exercises) and summative elements, consisting of a theoretical exam (accounting for 30% of the total grade) and a final capstone project (accounting for 70%).

RESULTS

The pedagogical manuscript is organized into the following thematic modules:

1. Physicochemical Properties, Thermodynamics, and Kinetics of Redox Reactions

This module covers the physicochemical properties of oxidizing agents, alongside the thermodynamic and kinetic principles of redox processes. Additionally, it examines the molecular mechanisms underlying the release of active oxygen, iodine, and chlorine in pharmaceutical substances and finished preparations.

2. Oxidimetric Analytical Methods for Pharmaceutical Quality Control

This module focuses on oxidimetric techniques used for the identification, purity testing, and quantitative determination of hydrogen peroxide, potassium permanganate, and iodine-containing compounds in accordance with the requirements of the State Pharmacopoeia of Ukraine (SPU).

3. Pharmaceutical Compatibility of Oxidizing Agents and Predictive Modeling of Incompatibilities

Within this framework, students evaluate how oxidizing agents interact with active pharmaceutical ingredients (APIs) and excipients, map out potential degradation pathways, and utilize predictive modeling tools to anticipate pharmaceutical incompatibilities.

4. Evaluation of the Effectiveness of Digital Technologies in Pharmaceutical Education

This module examines the pedagogical value of digital learning tools, virtual laboratories, simulations, learning management systems, and collaborative platforms in enhancing student engagement, competency development, and learning outcomes in pharmaceutical education.

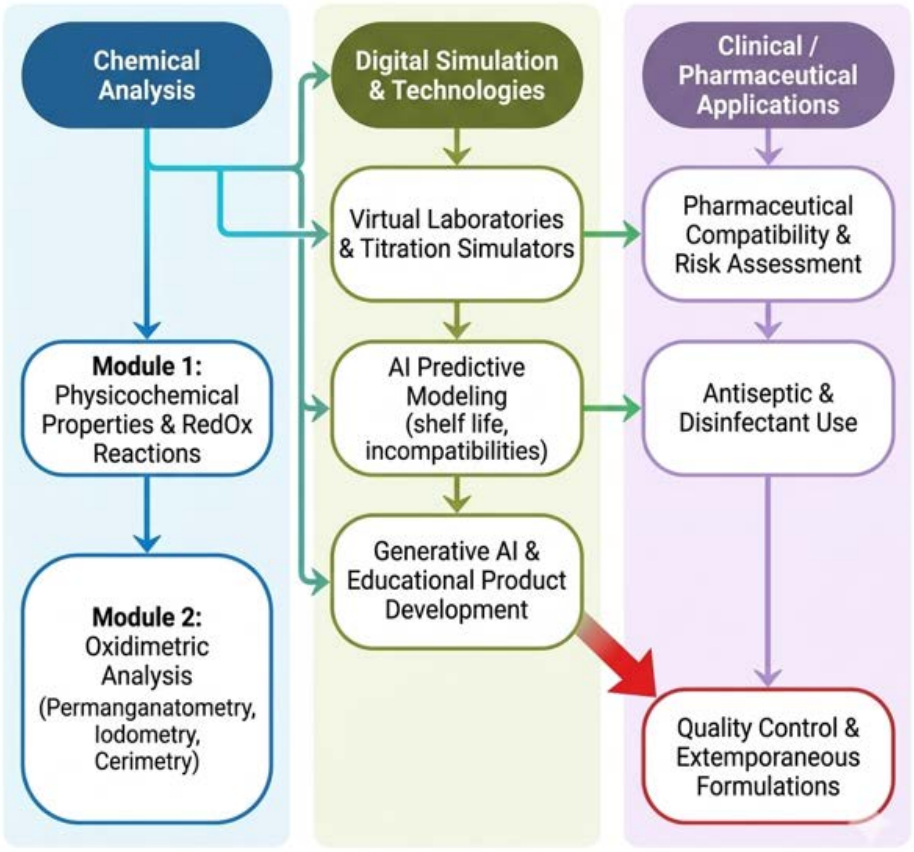

Figure 1. Schematic structure of the course modules showing the interconnections between chemical analysis, digital simulation, and clinical/ pharmaceutical application.

Key Components of the Pedagogical Manuscript

1. Theoretical Foundations with Current Scientific Evidence and References to the State Pharmacopoeia of Ukraine (SPU)

The manuscript contains a structured theoretical component dedicated to the physicochemical properties, mechanisms of action, and pharmaceutical applications of the major groups of oxidizing agents, including peroxides, halogens, manganese compounds, and related substances. Particular attention is paid to the requirements of the State Pharmacopoeia of Ukraine (SPU) regarding the standardization, quality control, and quantitative determination of oxidizing substances. The theoretical content is integrated with contemporary scientific literature, evidence-based data, digital knowledge repositories, and international pharmacopoeial approaches, ensuring both academic relevance and professional orientation of the learning process.

2. Practical Protocols and Virtual Titration Simulators

The practical component includes step-by-step laboratory protocols for oxidimetric analysis, such as permanganatometry, iodometry, and other analytical methods, adapted for blended and digital learning environments. To support the development of professional competencies, students engage with interactive simulators, video demonstrations, and virtual laboratories that enable them to practice titration procedures, interpret analytical results, and model typical laboratory scenarios in a safe environment. These digital tools provide opportunities for repeated practice, immediate feedback, and mastery of analytical techniques essential for pharmaceutical quality control.

3. Clinical and Pharmaceutical Case Studies with Compatibility Analysis

The manuscript incorporates problem-based and case-based learning activities focused on the application of oxidizing agents in pharmaceutical practice. Students analyze authentic and simulated clinical scenarios, evaluate the stability of pharmaceutical formulations, investigate pharmaceutical incompatibilities, and predict potential risks associated with extemporaneous compounding and drug preparation. Professional databases such as PubChem, DrugBank, and other scientific resources, together with chemical modeling software, are employed to support evidence-based decision-making and the development of critical professional judgment.

4. AI-Supported Assignments and the Capstone Project «Digital Oxidizing Agent Case Study»

The manuscript integrates generative artificial intelligence technologies to support the creation of educational content, visualizations, predictive models of oxidizing-agent behavior, and simulations of professional pharmaceutical scenarios. Students complete individual and collaborative assignments using tools such as ChatGPT, Claude, Gemini, and other AI platforms. The culminating learning activity is the capstone project, *«Digital Oxidizing Agent Case Study,»* in which students develop a comprehensive digital product. This project requires learners to analyze a selected oxidizing agent, model its pharmaceutical applications, evaluate its compatibility with excipients, assess potential risks, and present findings through an interactive case study, infographic, digital poster, or other multimedia format.

5. Self-Assessment, Peer Assessment, and Reflective Activities

The assessment system combines formative and summative approaches and is grounded in the principles of reflective learning. Students engage in self-assessment of their achievements according to the levels of Bloom's Taxonomy (application, analysis, evaluation, and creation), participate in peer review of case studies and projects, and maintain reflective records documenting their professional and digital development. The use of online surveys, electronic rubrics, and digital feedback platforms promotes self-regulated learning, critical thinking, reflective practice, and academic responsibility while fostering continuous improvement throughout the course.

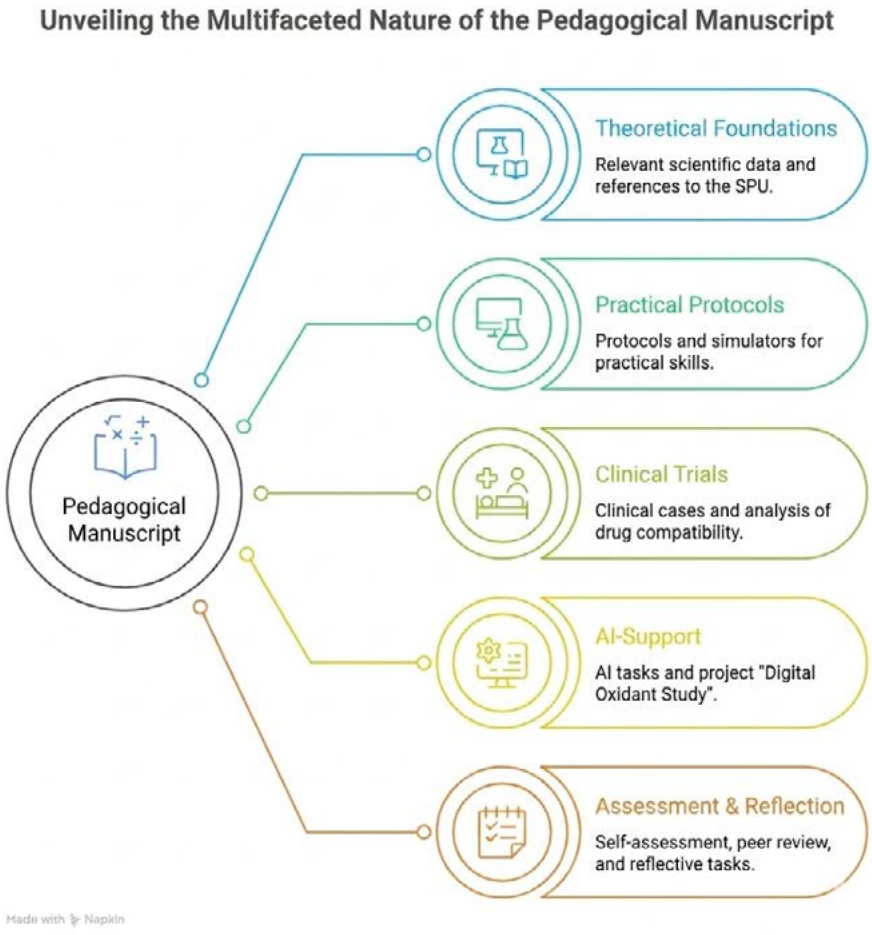

Figure 2. Unveiling the Multifaceted Nature of the Pedagogical Manuscript.

The course is delivered in a 30-hour hybrid format that combines asynchronous online learning, synchronous collaborative activities, and practice-oriented assignments. This model provides flexibility while maintaining active student engagement and continuous interaction with instructors and peers.

The theoretical component is supported by video lectures, multimedia learning materials, and short expert presentations that introduce key concepts related to oxidizing agents, pharmaceutical analysis, and clinical applications. To facilitate knowledge organization and conceptual understanding, students use interactive

mind maps that visualize relationships among chemical properties, analytical methods, mechanisms of action, pharmaceutical compatibility, and the therapeutic use of oxidizing agents.

To strengthen evidence-based learning and information literacy, students work with professional scientific databases, including PubChem and DrugBank, where they retrieve molecular, pharmacological, toxicological, and compatibility data. These resources enable learners to analyze the physicochemical characteristics of oxidizing substances and connect laboratory findings with pharmaceutical and clinical practice.

The digital learning process is coordinated through the Moodle Learning Management System (LMS), which serves as the central hub for course materials, assignments, quizzes, assessments, discussion forums, and progress monitoring. Moodle supports personalized learning pathways and provides continuous formative feedback throughout the course.

Collaborative learning activities are implemented through digital platforms such as Padlet and Miro. These tools facilitate group discussions, collaborative problem-solving, brainstorming sessions, visual mapping of pharmaceutical cases, and peer review of project work. Students jointly develop analytical frameworks, evaluate compatibility scenarios, and present their findings in interactive digital formats.

A distinctive feature of the course is the integration of generative artificial intelligence (AI) tools, including ChatGPT, Gemini, and Claude. These technologies are used to support content creation, generate visual explanations and infographics, simulate professional pharmaceutical scenarios, develop case studies, and provide personalized learning assistance. Students critically evaluate AI-generated outputs, compare them with scientific evidence and pharmacopoeial standards, and learn to apply AI responsibly in academic and professional contexts.

Through the combination of digital resources, collaborative platforms, virtual simulations, and AI-assisted learning, the hybrid format promotes the development of professional, analytical, digital, and research competencies essential for modern pharmaceutical practice.

DISCUSSION

The developed educational manuscript represents a significant contribution to the reformation of higher medical and pharmacy education, as it effectively addresses existing systemic gaps in the training of modern pharmacists. The core value of this material lies in creating a comprehensive, integrated educational resource that successfully bridges the traditional divide between fundamental chemical theory and its practical application in analytical workflows and clinical practice. Rather than studying dry chemical formulas and reactions in isolation, students are offered an end-to-end approach where every molecular concept is immediately projected onto real-world therapeutic scenarios, bioavailability assessments, and individualized patient needs.

The conceptual architecture of the proposed curriculum is fully aligned with advanced global standards. Emulating the personalized, practice-oriented educational pathways that traditionally yield high efficiency in modern medical residency and training, this course departs from outdated, one-size-fits-all learning models. Through the implementation of agile digital platforms and adaptive tools, each student can progress at their own pace, focusing more deeply on complex or highly specialized areas of interest. Special emphasis is placed on project-based learning and case-study problem-solving in teams, which simulates the actual atmosphere of pharmaceutical manufacturing or clinical consultations where decisions must be made swiftly and collaboratively.

During the development and implementation of this program, the authorial team faced several serious methodological and logistical challenges. The first was the need to strike an ideal balance between academic rigor – the deep theoretical basis of bioorganic or analytical chemistry – and the clarity, visibility, and accessibility of this material for student comprehension. The second, equally demanding task was ensuring safety during practical training: working with aggressive, corrosive, and toxic reagents always carries risks, creating a need for high-tech virtual simulations that allow students to practice and learn from mistakes in a safe digital environment without risking their health. Finally, the third challenge was the sheer dynamism of science itself – amidst the rapid evolution of pharmacogenomics, the emergence of biotechs, and the daily updates to clinical protocols, it was critically important to maintain absolute scientific accuracy and relevance while embedding a flexible structure for rapid content updates.

Despite these difficulties, the synergy of classical pedagogy and modern technology successfully overcame these hurdles. The integration of structured mentorship, where experienced faculty and practicing professionals guide students at every stage, combined with peer-review elements among the students themselves, created a healthy and supportive educational ecosystem. Additionally, AI-driven tools served as a powerful catalyst, utilized for analyzing large datasets, predicting molecular interactions, and optimizing routine analytical processes. Ultimately, this comprehensive approach successfully fostered advanced critical thinking, evidence-based practice skills, a deep sense of professional responsibility toward society, and a readiness for continuous

innovation. These integrated competencies are absolutely indispensable and key for competitive specialists aiming to thrive in the high-tech landscape of contemporary global pharmacy.

CONCLUSIONS

The educational manuscript developed for the highly specialized course «Oxidizing Agents in Pharmacy: From Chemical Analysis to Clinical Application» represents a pioneering pedagogical instrument designed to fundamentally transform the paradigm of modern pharmaceutical education. Historically, higher education in pharmacy has suffered from a distinct compartmentalization, where fundamental chemical disciplines and clinical practice are taught in isolation. This manuscript systematically dismantles those traditional silos by introducing a robust, interdisciplinary framework that seamlessly bridges the gap between laboratory-scale analytical chemistry and real-world clinical pharmacy. By contextualizing the reactivity, stability, and mechanisms of oxidizing agents – ranging from classic disinfectants to complex redox-active therapeutics – the curriculum ensures that abstract molecular concepts are immediately tethered to tangible pharmaceutical outcomes, quality control metrics, and patient safety protocols.

At the core of this curriculum is an emphasis on digital transformation and adaptive learning, shifting the student's role from a passive consumer of information to an active investigator and innovator. The course leverages cutting-edge simulation technologies and virtual laboratory environments to safely replicate high-stakes scenario analysis. This is particularly crucial when dealing with potent oxidizing agents, where real-world mishandling can lead to dangerous exothermic reactions, chemical degradation, or hazardous laboratory conditions. Furthermore, the integration of generative artificial intelligence (AI) serves as a sophisticated cognitive scaffold. Students utilize AI-driven tools not merely as automated shortcuts, but as analytical partners to simulate complex molecular interactions, optimize oxidimetric titration parameters, and actively develop their own digital educational products, thereby reinforcing their conceptual mastery through peer-to-peer knowledge transfer.

This comprehensive approach deliberately prepares future-ready professionals to navigate the multi-faceted demands of the modern healthcare and industrial landscapes. In the laboratory and manufacturing spheres, the curriculum instills high-level proficiency in advanced oxidimetric analysis techniques, which are foundational for rigorous quality control, regulatory compliance, and the rapidly growing sector of biotechnological manufacturing. Simultaneously, from a clinical and compounding perspective, students are equipped with the advanced critical thinking skills required to predict and manage complex pharmaceutical incompatibilities, prevent the accidental oxidation of sensitive active pharmaceutical ingredients (APIs), and safely execute extemporaneous compounding. By synthesizing rigorous analytical chemistry with the agility of digital tools and clinical foresight, this manuscript provides a scalable blueprint for nurturing highly competent, adaptable, and forward-thinking pharmacy professionals.

Perspectives for further research. Future research and developmental efforts should focus on expanding the integration of artificial intelligence components, specifically through the implementation of adaptive AI-driven tutors and predictive analytics to track student progress in real time. Additionally, conducting broader multi-center pilot testing across diverse student cohorts is essential to gather robust empirical data, validate the curriculum's metrics, and evaluate its long-term impact on clinical reasoning. Finally, continuous alignment with international educational standards, global regulatory requirements (such as EMA and FDA guidelines), and rapid technological advancements is crucial to ensure that pharmaceutical and biotechnological education remains dynamically synchronized with the evolving demands of the modern healthcare industry.

COMPLIANCE WITH ETHICAL REQUIREMENTS

The development and implementation of this pedagogical manuscript comply with the ethical principles of the Declaration of Helsinki and the institutional bioethical standards of the university. The use of digital technologies, online learning environments, and artificial intelligence tools is conducted in accordance with the principles of academic integrity, chemical safety, and data protection. Students are encouraged to critically evaluate AI-generated content, appropriately acknowledge digital resources, and adhere to ethical standards in scientific communication and professional practice. All learning activities involving virtual simulations, case studies, and digital platforms are designed to ensure responsible use of technology, respect for intellectual property, and the protection of personal and educational data.

Study limitations. Several constraints should be acknowledged regarding the scope of this work. First and foremost, our analysis focuses predominantly on the structural and conceptual framework of the newly developed teaching manual, meaning that long-term empirical metrics tracking actual student knowledge retention or final exam performance over multiple academic years are not yet available. Furthermore, the implementation and initial validation of these course parameters were conducted exclusively within a single institution – Bogomolets National Medical University. Consequently, caution should be exercised when extrapolating these outcomes to diverse multi-center educational settings. Finally, given the blistering pace at

which generative AI tools and virtual simulation software advance, specific prompt sequences and digital platforms utilized during the 2025-2026 academic terms will naturally require regular adjustments to remain aligned with subsequent software updates.

Primary data and materials. The core curriculum architectures, thematic outlines, module schedules, and assessment rubrics established for the course are documented extensively within the body text and figures of this paper. The underlying digital learning materials, course shells, and interactive configurations deployed on the Moodle LMS platform represent intellectual and programmatic outputs designed under the auspices of the ERASMUS+ UkraineDigiTrans initiative. Because these resources are integrated into institutional frameworks, they cannot be made fully public, yet anonymized components or specific syllabi templates can be obtained from the corresponding author upon a reasonable request for non-commercial educational use.

Declaration of AI use. The authors explicitly state that generative artificial intelligence models (including ChatGPT, Claude, and Gemini) were employed during the final drafting stage of this paper solely as supportive linguistic tools. This intervention was strictly confined to smoothing the stylistic flow of the English phrasing, correcting minor grammatical nuances, and ensuring the prose meets international editorial benchmarks. The entire conceptual foundation of the course, the design of the pedagogical modules, the scientific arguments, and the overarching conclusions were independent human efforts generated by the co-authors. The human authorial team retains complete responsibility for the veracity, originality, and academic compliance of the final text.

FUNDING AND CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the objectivity of the research findings presented in this study.

AUTHOR CONTRIBUTIONS

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Резюме

ОСОБЛИВОСТІ РОЗРОБКИ ПЕДАГОГІЧНОГО МАНУСКРИПТУ КУРСУ «ОКИСНИКИ В ФАРМАЦІЇ: ВІД ХІМІЧНОГО АНАЛІЗУ ДО КЛІНІЧНОГО ЗАСТОСУВАННЯ» ДЛЯ МАЙБУТНІХ ФАРМАЦЕВТІВ ТА БІОТЕХНОЛОГІВ У МЕЖАХ ПРОЄКТУ ERASMUS+ UKRAINEDIGITRANS

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Вступ. Для вирішення проблеми дефіциту матеріалів, що інтегрують хімічну теорію, клінічну практику та цифрові інструменти, це дослідження вивчає розробку манускрипту для курсу «Окисники в фармації» та його потенціал щодо підвищення компетентностей студентів спеціальностей фармації та біотехнології за допомогою ШІ та симуляційних технологій.

Мета. Дослідити організаційні, методологічні та цифрові особливості розробки цього навчального манускрипту та оцінити його вплив на формування професійних компетентностей, аналітичних навичок і клінічного мислення.

Матеріали та методи. Манускрипт розроблено на основі систематичного аналізу наукової літератури (2020-2026 рр.), узгодження з вимогами Державної Фармакопеї України (ДФУ) та перегляду чинних навчальних програм з фармації. Модульна, компетентнісно-орієнтована структура містить 5 чітких результатів навчання, що відповідають рівням таксономії Блума. Курс (обсягом 1 кредит ЄКТС, 30 годин, гібридний формат) розрахований на студентів 2-го та 3-го курсів бакалаврату/магістратури, які навчаються за спеціальностями «Фармація, промислова фармація» та «Біотехнології та біоінженерія». Цифрові інструменти були інтегровані в архітектуру курсу, а збір зворотного зв'язку здійснювався за допомогою опитувань та LMS. Обробка даних включає дескриптивний аналіз відповідності змісту.

Результати. Розроблений манускрипт інтегрує фізико-хімічні властивості та механізми дії окисників (пероксиди, галогени, солі марганцю), методи оксидиметричного аналізу (перманганатометрія, йодометрія, цериметрія), аналіз фармацевтичної сумісності та клінічні аспекти. Особливий акцент зроблено на цифрових симуляціях і віртуальних лабораторіях для безпечного навчання титруванню, штучному інтелекті (ШІ) для прогностичного моделювання несумісностей і розробці самими студентами навчальних продуктів, таких як «Цифрові кейси з вивчення окисників» (Digital Oxidizer Case Studies). Архітектура курсу охоплює теоретичні модулі, кейс-методи та фінальний капстоун-проєкт (який становить 70% від підсумкової оцінки). Для підтримки практико-орієнтованого навчання використовуються такі платформи, як Canva, Padlet, Moodle, генеративний ШІ та симулятори титрування.

Висновки. Сучасний навчальний манускрипт ефективно модернізує фармацевтичну освіту, забезпечуючи плавний перехід від базового хімічного аналізу до клінічної та фармацевтичної практики. Інтеграція гібридного формату навчання, симуляційних технологій та штучного інтелекту (ШІ) сприяє розвитку критичного мислення, професійної етики, хімічної безпеки, а також готовності до виконання завдань з контролю якості ліків та виготовлення екстемпоральних лікарських форм. Рекомендовано постійне вдосконалення навчальної програми на основі даних про успішність студентів та з урахуванням поточного технологічного прогресу.

Ключові слова: **навчальний манускрипт; фармацевтична освіта; біотехнологія; окисники; оксидиметричний аналіз; цифрова педагогіка; симуляційні технології; штучний інтелект; індивідуалізоване навчання**

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