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DEVELOPING DIGITAL COMPETENCE OF FUTURE BIOLOGY TEACHERS IN THE CONTEXT OF KAZAKHSTAN'S EDUCATIONAL MODERNIZATION

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This article examines the development of digital competence among future biology teachers in the context of Kazakhstan's educational modernization. The aim of the research is to identify the structural components of digital competence and outline the process of its formation among prospective biology teachers. The study argues that digital competence is not limited to basic technical skills, but includes informational literacy, pedagogical use of digital tools, and ethical responsibility in digital environments. Given the complexity of biological content and increasing shift toward digital-pedagogical formats, integration of technological tools becomes essential for visualization, simulation, and interactive analysis of biological processes. The paper demonstrates that traditional instruction often cannot meet these demands, especially when laboratories or material resources are limited, while digital tools (virtual labs, 3D models, simulations, data visualizations) open up new pedagogical possibilities. The research underlines practical and scientific significance: improving teacher training to meet contemporary digital demands and aligning biology education with global scientific practices. The contribution lies in proposing a comprehensive model of digital competence with differentiated levels of development (basic, functional, creative), which can inform curriculum design, pedagogical training, and assessment frameworks in teacher education institutions.

Keywords: digital competence; biology education; digital pedagogy; teacher training; higher education; educational transformation

Introduction

The rapid intensification of digital transformation in modern society has redefined the professional profile of teachers and reshaped the structure of pedagogical education. [1][2]. In Kazakhstan, this transformation is closely connected with national strategies aimed at modernizing the educational system, expanding technological infrastructure, and enhancing the global competitiveness of higher education. [3][5]. Future teachers, particularly those specializing in biology, are expected to develop the ability to navigate digital environments with confidence, to employ technological tools in pedagogically meaningful ways, and to cultivate in students the skills required to participate in a knowledge-oriented, information-rich world. As biology encompasses complex, multilevel systems that are often inaccessible to direct observation, digital tools offer unique pedagogical opportunities and enrich subject-specific understanding. [6][7][8]. This creates a new professional reality in which digital competence becomes an essential attribute of a qualified biology teacher.

Digital competence in teacher education extends far beyond the conventional understanding of digital literacy. It involves a sophisticated synthesis of knowledge, technical skills, pedagogical reasoning, and ethical awareness. [10] [11]. For a future biology teacher, digital competence represents not merely an operational familiarity with digital devices but a conceptual framework for understanding how digital instruments can mediate the learning of biological content. The contemporary biology classroom is increasingly conceptualized as a dynamic, interactive environment where students engage with data visualizations, virtual experiments, digital models, and analytical tools that simulate real scientific inquiry. [12][13]. In such an environment, the teacher must be capable of selecting appropriate digital resources, interpreting scientific information embedded in digital formats, and constructing learning experiences that cultivate curiosity, inquiry, and critical thinking.

Materials and Methods

The current stage of digitalization has made biological knowledge more accessible and more complex at the same time. A significant portion of biological content requires visualization of microscopic structures, modeling of physiological mechanisms, and simulation of ecological processes. [1][2][5]. Traditional forms of instruction are often insufficient for these tasks, as they depend on material resources that may be limited or unavailable in typical schools. For instance, cell division, gene expression, molecular interactions, and population dynamics cannot be easily reproduced in a classroom without advanced laboratory facilities. Digital tools overcome these limitations by offering virtual microscopes, interactive 3D anatomical models, dynamic ecological simulations, and software environments that allow students to manipulate variables and observe the consequences in real time. [6][7][8]. These technologies not only replicate laboratory experiences but also extend them, providing students with safe, repeatable, and customizable experimental conditions. For this reason, digital competence is especially relevant for biology teachers, whose professional responsibilities increasingly involve orchestrating technologically enriched learning environments.

Despite the recognized importance of digital competence, its formation in pedagogical universities in Kazakhstan remains uneven and complex. Differences in institutional infrastructure persist, affecting access to devices, software, and stable internet connectivity. In major universities located in urban centers, digital laboratories, multimedia classrooms, and high-quality digital repositories are more widely available. In contrast, institutions in regional areas often confront challenges related to outdated equipment, insufficient funding, or limited access to specialized biological software. Infrastructure inequalities create disproportions in students' learning opportunities, which subsequently influence their professional readiness. As digital competence is not merely a theoretical concept but a practice-dependent attribute, the absence of high-quality digital environments restricts the development of essential skills. [9][10].

Another factor contributing to the uneven formation of digital competence concerns the readiness of university instructors. Faculty members play a critical role in shaping students' digital habits and perceptions of technology's pedagogical potential. However, instructors themselves exhibit diverse levels of digital proficiency. Some demonstrate strong engagement with digital technologies, incorporating interactive simulations, virtual experiments, and digital forms of assessment into their teaching practices. Others rely predominantly on traditional methods, integrating technology only minimally or episodically. Variability in instructors' digital competence results in inconsistent exposure of students to digital pedagogical practices, which affects their ability to conceptualize the role of technology in their future professional work. Because digital competence includes not only technical proficiency but also pedagogical reasoning and instructional design, instructor modeling is essential for building students' confidence in digital environments.

Curricular structure also influences the development of digital competence. While pedagogical universities include courses related to information and communication technologies, these courses frequently adopt a generalist orientation and do not sufficiently address the subject-specific needs of future biology teachers. Students may learn the theoretical foundations of digital tools or basic computer literacy but receive limited practice applying these tools within biological contexts. As a result, digital technologies are perceived as supplementary rather than integral to subject teaching. Integrating technology directly into biology methodology courses—where students design lessons, analyze biological data, and create digital learning resources—would align digital training with subject-specific professional requirements. [11][12][13][14][15]. Without this alignment, digital competence develops in fragmented ways, detached from the realities of everyday teaching practice.

To understand the structural complexity of digital competence, it is necessary to examine the conceptual components that collectively define this professional construct. Digital competence comprises technical expertise, informational literacy, pedagogical application, and ethical responsibility. Technical expertise includes the ability to operate digital platforms, software, and devices relevant to biology instruction. Informational literacy refers to the capacity to locate, interpret, and evaluate digital information, including scientific datasets, biological visualizations, and research results. Pedagogical application concerns the integration of digital tools into lesson planning, instruction, assessment, and inquiry-based learning. [14][15][17]. Ethical responsibility encompasses the safe, responsible, and sustainable use of digital resources, including concerns about academic integrity, privacy, and the credibility of digital information sources. A conceptual visualization of this structure is presented in Figure 1.

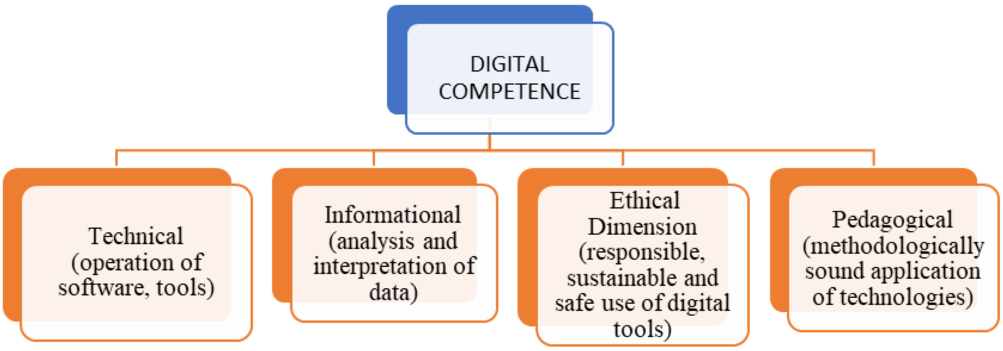

Figure 1. Structural Model of Digital Competence of Future Biology Teachers

Results. The development of digital competence is a dynamic and multi-layered process that unfolds through gradual progression. At the basic level, students become familiar with fundamental digital operations and develop rudimentary confidence in navigating educational platforms. This level is essential but insufficient for the demands of contemporary biology education. At the functional level, students begin to integrate digital tools into the design and implementation of biology lessons. They use interactive models to explain cellular structures, incorporate simulations to demonstrate physiological processes, and apply digital datasets to facilitate ecological analysis. At the creative level, students acquire the ability to independently design and construct digital educational resources, such as virtual laboratory activities, automated assessment tools, and interactive conceptual models. The distinction between these levels is pedagogically significant because it reflects the shift from passive use of digital tools to active, innovative, and contextually meaningful integration. These levels are summarized in Table 1.

Table 1. Levels of Digital Competence of Future Biology Teachers

Level	Description	Application in Biology
Basic	Simple operational tasks	LMS usage, basic digital materials
Functional	Integrated pedagogical use	Simulations, models, data visualization
Creative	Independent digital resource creation	Virtual labs, digital assessments

Achieving higher levels of digital competence requires systemic support from educational institutions. Curriculum modernization is essential; as digital tools must be embedded meaningfully into methodological training rather than treated as isolated supplemental topics. Programs should emphasize the development of lesson planning strategies that incorporate digital resources, digital assessment methods, and digital-supported inquiry-based activities. Such integration ensures that students learn not only how to operate technology but also how to use it to support conceptual understanding and scientific reasoning.

Faculty development is another foundational area for improvement. Universities must provide ongoing professional development programs that address both technical and pedagogical aspects of digital technology. Instructors who regularly use interactive simulations, virtual lab environments, and data analysis tools are better positioned to cultivate digital competence among their students. The presence of digitally competent faculty members creates a culture of technological innovation that benefits the entire academic community.

Assessment of digital competence is also critical. Kazakhstan currently lacks standardized evaluation tools capable of measuring the digital readiness of future teachers. Assessment systems must reflect the multidimensional nature of digital competence and move beyond testing operational skills. Effective evaluation mechanisms could include digital portfolios, performance-based tasks, microteaching sessions incorporating digital technologies, and reflections on pedagogical decision-making in digital environments. International frameworks such as DigCompEdu, TPACK, and the UNESCO ICT Competency Framework offer useful models for designing assessment instruments tailored to local needs.

In addition to internal educational reforms, digital competence must be contextualized within broader global trends in biology education. Contemporary scientific communication increasingly relies on digital formats, large datasets, and computational methods. Authentic scientific practices in fields such as genomics, ecology, and neuroscience depend heavily on digital tools, from advanced imaging systems to data analytics platforms. Introducing future teachers to these tools during their university training equips them with relevant competencies and aligns educational practice with modern scientific realities. For example, ecological data visualizations extracted from real scientific repositories can be used to illustrate population dynamics or climate-related changes in ecosystems. Virtual experiments allow students to explore genetic inheritance or biochemical reactions without the constraints of laboratory resources. Thus, digital competence becomes not only a pedagogical requirement but also a bridge between school-level biology and contemporary scientific research.

Ethical considerations form another essential component of digital competence. As teachers increasingly rely on digital platforms, they must ensure the responsible use of student data, respect intellectual property rights, and maintain academic integrity. Teaching students to critically evaluate digital sources, question the credibility of online biological information, and understand ethical issues related to scientific knowledge is an integral part of digital pedagogy. Future biology teachers must model responsible digital behavior, demonstrate the importance of accuracy, transparency, and critical thinking when interact with scientific content.

The modernization of Kazakhstan's educational system positions digital competence as a foundational element of professional teacher training. Achieving widespread digital readiness requires coordinated efforts across curriculum development, institutional infrastructure, faculty preparation, and assessment systems. As digital technologies continue to evolve, biology education must adapt by incorporating digital tools that support inquiry-based learning, deepen conceptual understanding, and reflect current scientific practices. Preparing future biology teachers to operate confidently in digital environments ensures that they can foster scientifically literate, technologically competent, and critically thinking learners.

Conclusion

Digital competence is a vital dimension of the professional preparation of future biology teachers in Kazakhstan. Its development requires more than exposure to technology; it demands coherent pedagogical integration, a supportive institutional environment, and a systematic approach to curriculum, instruction, and assessment. Digital tools offer unprecedented opportunities to enrich biology education, but their potential can be realized only when teachers possess the skills and confidence to use them effectively. The continued modernization of teacher education in Kazakhstan will depend on expanding access to digital resources, strengthening faculty digital readiness, implementing unified assessment frameworks, and ensuring that students engage in meaningful, practice-oriented digital learning experiences. With sustained institutional support and thoughtful pedagogical innovation, future biology teachers will be able to participate fully in the transformation of contemporary education and contribute to the advancement of scientifically robust and digitally enriched learning environments.

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РАЗВИТИЕ ЦИФРОВОЙ КОМПЕТЕНТНОСТИ БУДУЩИХ УЧИТЕЛЕЙ БИОЛОГИИ В КОНТЕКСТЕ МОДЕРНИЗАЦИИ ОБРАЗОВАНИЯ КАЗАХСТАНА

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В статье рассматривается развитие цифровой компетентности будущих учителей биологии в контексте модернизации образования в Казахстане. Цель исследования - выявить структурные компоненты цифровой компетентности и проследить процесс её формирования среди студентов-биологов. Автор(ы) понимают цифровую компетентность не просто как технические навыки, а как совокупность: информационной грамотности, педагогического использования цифровых инструментов и ответственности в цифровой среде. В условиях усложнения содержания по биологии и перехода к цифровым форматам обучения использование технологических средств (виртуальные лаборатории, 3D-модели, симуляции, визуализация данных) становится необходимым для усвоения сложных тем. Работа подчёркивает научную и практическую значимость - подготовку учителей, отвечающих современным требованиям, и сближение школьной биологии с актуальными научными практиками. Вклад исследования - предложенная комплексная модель цифровой компетентности с уровнями «базовый - функциональный - креативный», что может быть использовано при разработке учебных планов, педагогической подготовки и систем оценки в вузах.

Ключевые слова: цифровая компетентность; биологическое образование; цифровая педагогика; подготовка учителей; высшее образование; образовательная трансформация

ҚАЗАҚСТАН БІЛІМ БЕРУ ЖҮЙЕСІН ЖАҢҒЫРТУ КОНТЕКСТІНДЕ БОЛАШАҚ БИОЛОГИЯ МҰҒАЛІМДЕРІНІҢ ЦИФРЛЫҚ ҚҰЗЫРЕТТІЛІГІН ДАМЫТУ

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Бұл мақала Қазақстандағы білім беру модернизациясы жағдайында болашақ биология мұғалімдерінің цифрлық біліктілігін дамыту мәселесін қарастырады. Зерттеу мақсаты – цифрлық біліктіліктің құрылымдық компоненттерін анықтау және оның болашақ биология мұғалімдері арасында қалыптасу үдерісін сипаттау. Мақала цифрлық біліктілікті тек техникалық дағдылармен шектелмейтін, сонымен қатар ақпараттық сауаттылықты, цифрлық құралдарды педагогикалық қолдануды *және цифрлық ортадағы этикалық жауапкершілікті қамтитын тұтас кәсіби қасиет ретінде қарастырады. Биологиялық мазмұнның күрделілігі және цифрлық-педагогикалық форматтарға көшу жағдайында, виртуалды лабораториялар, 3D модельдер, симуляциялар мен деректер визуализациясы арқылы білім беру әдістерін байыту қажеттілігі артады. Мақала дәстүрлі оқыту әдістерінің шектеулерін көрсетеді және цифрлық құралдар қолданудың педагогикалық мүмкіндіктерін ашады. Ғылыми және практикалық маңызы – мұғалімдерді қазіргі цифрлық талаптарға сай даярлау, биология білімін жаһандық ғылыми тәжірибемен сәйкестендіру. Ұсынған модель (базалық, функционалдық, шығармашылық деңгейлер) оқу жоспарларын, педагогикалық дайындық пен бағалау жүйесін жетілдіруге үлес қосады.*

Кілт сөздер: цифрлық құзыреттілік; биологияны оқыту; цифрлық педагогика; мұғалімдерді даярлау; жоғары білім; білім беру трансформациясы