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IRSTI 14.35.07

UDC 378.14.015.62

<https://doi.org/10.52269/SEPT2632068>

DIDACTIC INTEGRATION OF DIGITAL TECHNOLOGIES IN PHYSICS TEACHER EDUCATION

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Amid the rapid digitalization of education, the use of information and communication technologies (ICT) in physics education is no longer limited to proficiency in individual digital tools and requires a didactic understanding of their application. However, the mere availability of digital technologies in the educational process does not, in itself, guarantee their pedagogical appropriateness or methodological integration into lesson structure. The aim of this study is to analyze undergraduate educational programs for pre-service physics teacher education in terms of the extent to which they include courses focused on the pedagogically grounded use of ICT in instructional design. The empirical basis includes 20 educational programs in the B010 «Physics Teacher Training» group. The analysis is based on a formalized content analysis of discipline titles and the calculation of integral indices reflecting digital, experimental, and research orientation. The results indicate that, despite the consistent presence of experimental and research-oriented courses, the didactically grounded integration of digital technologies is fragmented and, in most cases, remains primarily instrumental in nature. The overwhelming majority of educational programs do not include courses explicitly focused on the methodologically informed use of ICT in physics education. These findings substantiate the need to develop an interdisciplinary core in pre-service physics teacher education that ensures coherence among the subject-specific, methodological, and digital components of professional preparation. The findings may also be used to inform the improvement of teacher education programs.

Keywords: training of future physics teachers, ICTs in education, digital technologies, educational programs, design.

ФИЗИКА МҒАЛІМДЕРІН ДАЯРЛАУДАҒЫ ЦИФРЛЫҚ ТЕХНОЛОГИЯЛАРДЫҢ ДИДАКТИКАЛЫҚ ИНТЕГРАЦИЯСЫ

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Білім беруді белсенді цифрландыру жағдайында физиканы оқытуда ақпараттық-коммуника-

циялық технологияларды қолдану мәселесі жеке құралдарды қолдана алу мүмкіндігінен асып түседі және дидактикалық мақсаттылықты қажет етеді. Оқу процесінде цифрлық құралдардың қолданылуы олардың педагогикалық орындылығына және сабақтың құрылымына әдістемелік сәйкес келуіне кепілдік бермейді. Зерттеудің мақсаты физика мұғалімдерін даярлауды жүзеге асыратын бакалавриаттың білім беру бағдарламаларын оларда оқу сабақтарын жобалау кезінде АКТ-ны дидактикалық негізделген қолдануға бағытталған пәндер қаншалықты ұсынылғаны тұрғысынан талдау болып табылады. Зерттеудің эмпирикалық базасы В010 «Физика мұғалімдерін даярлау» тобының 20 білім беру бағдарламасы болды. Талдау пәндердің атауларын формальды контент-талдау негізінде, сонымен қатар бағдарламалардың цифрлық, эксперименттік және зерттеу бағытының деңгейін көрсететін интегралдық индекстерді есептеу негізінде орындалды. Талдау нәтижелері эксперименттік және зерттеу қызметіне бағытталған пәндердің білім беру бағдарламаларында болуына қарамастан, цифрлық технологиялардың дидактикалық бағытталған интеграциясы фрагментті түрде ұсынылатынын және көп жағдайда инструменталды сипатта болатынын көрсетті. Білім беру бағдарламаларының басым көпшілігінде физиканы оқытуда АКТ-ны әдістемелік мағыналы қолдануға тікелей бағытталған пәндер жеткіліксіз. Алынған нәтижелер кәсіби даярлықтың пәндік, әдістемелік және цифрлық компоненттерінің үйлесімділігін қамтамасыз ететін болашақ физика мұғалімдерін даярлаудың пәнаралық өзегін дамыту қажеттілігін негіздейді және педагогикалық бейіндегі білім беру бағдарламаларын жетілдіруде пайдаланылуы мүмкін.

Түйінді сөздер: болашақ физика мұғалімдерін даярлау, білім берудегі АКТ, цифрлық технологиялар, білім беру бағдарламалары, жобалау.

ДИДАКТИЧЕСКАЯ ИНТЕГРАЦИЯ ЦИФРОВЫХ ТЕХНОЛОГИЙ В ПОДГОТОВКУ УЧИТЕЛЕЙ ФИЗИКИ

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В условиях активной цифровизации образования вопрос использования информационно-коммуникационных технологий в обучении физике выходит за рамки владения отдельными инструментами и требует дидактического осмысления. Однако наличие цифровых средств в учебном процессе само по себе не гарантирует их педагогической целесообразности и методической встроенности в структуру урока. Целью данного исследования является анализ образовательных программ бакалавриата, реализующих подготовку учителей физики, с точки зрения того, в какой степени в них представлены дисциплины, ориентированные на дидактически обоснованное использование ИКТ при проектировании учебных занятий. Эмпирическую базу исследования составили 20 образовательных программ группы В010 «Подготовка учителей физики». Анализ выполнен на основе формализованного контент-анализа наименований дисциплин с последующим расчётом интегральных индексов, отражающих уровень цифровой, экспериментальной и исследовательской направленности программ. Полученные результаты показывают, что при устойчивом присутствии экспериментальных и исследовательских дисциплин дидактически ориентированная интеграция цифровых технологий представлена фрагментарно и в большинстве случаев носит инструментальный характер. В подавляющем числе образовательных программ отсутствуют дисциплины, прямо ориентированные на методически осмысленное использование ИКТ в обучении физике. Полученные результаты обосновывают необходимость развития междисциплинарного ядра подготовки будущих учителей физики, обеспечивающего связность предметных, методических и цифровых компонентов профессиональной подготовки, и могут быть использованы при совершенствовании образовательных программ педагогического профиля.

Ключевые слова: подготовка будущих учителей физики, ИКТ в образовании, цифровые технологии, образовательные программы, проектирование.

Introduction. The rapid expansion of information and communication technologies has led to profound changes in contemporary education, affecting not only teaching tools but also the logic of lesson design and the professional role of the teacher. In school physics education, digital technologies are increasingly used for visualization, modeling, data acquisition, and experimental analysis. However, the educational value of these tools depends not on their availability, but on the teacher's ability to integrate them into the structure and objectives of the lesson in a pedagogically meaningful way.

A number of studies emphasize that future teachers generally demonstrate a sufficient level of basic skills related to lesson planning. For example, Süral [1, pp. 8, 11–12] reports that pre-service teachers demonstrate an overall adequate level of competence in lesson planning, while emphasizing the importance of strengthening their practical preparation and curriculum literacy. Similar conclusions are drawn by Gill, Dalgarno, and Carlson [2, pp. 53–54], who demonstrate that, over the course of their teacher education

program, pre-service teachers generally progress from an uncritical acceptance of observed ICT practices towards a more reflective and context-sensitive understanding of technology use, although the pace and extent of this development vary considerably among students.

In the context of physics teacher education, the problem becomes more specific. Physics teaching traditionally relies on experimentation, modeling, and the interpretation of empirical data, all of which are increasingly mediated by digital tools. Consequently, the professional training of future physics teachers requires not only general digital literacy, but also the ability to align digital resources with subject content, experimental activity, and didactic objectives. Despite this, the preparation of teachers for such integrated use of ICT remains uneven and often fragmented.

Previous research has identified a wide range of factors influencing teachers' readiness to use ICT. These include institutional and material conditions, such as access to digital tools, laboratory equipment, and specialized software [3], as well as organizational support and institutional culture [4]. Other studies focus on individual characteristics of teachers, including their level of digital competence [5], technology–pedagogy–content knowledge [6], professional experience [7], and psychological readiness to adopt digital tools, such as self-efficacy and attitudes toward technology use [8].

At the same time, several authors note that effective technology integration cannot be reduced to technical proficiency alone. Janssen and Lazonder [9, p. 456] argue that pre-service teachers often experience difficulty integrating technological, pedagogical, and content information, which may result in low-quality technology integration in their lesson plans. Similar conclusions are presented in studies emphasizing that mastery of digital tools becomes pedagogically meaningful only when it is embedded in lesson design and supported by methodological training [10–12].

The analysis of existing research shows that, despite the growing body of literature on ICT in teacher education, an important aspect remains insufficiently explored. Most studies focus either on general digital competence or on individual pedagogical conditions, while the structural characteristics of teacher education programs themselves receive considerably less attention. In particular, there is a lack of empirical analyses examining how didactically oriented ICT components are embedded in the curricula of physics teacher education programs and how these components relate to subject-specific, methodological, and experimental training.

Therefore, research aimed at analyzing the structure of physics teacher education programs from the perspective of didactically grounded ICT integration remains relevant. Such analysis allows one to move beyond declarative statements about digitalization and to identify actual approaches used in curriculum design.

The aim of this study is to identify the extent and nature of didactically oriented use of information and communication technologies in bachelor's degree programs that train future physics teachers, as well as to analyze how digital tools are incorporated into the structure of subject-specific, methodological, and experimental training.

To achieve this aim, the following **objectives** were addressed:

- 1) To analyze the lists of academic disciplines included in physics teacher education programs and determine the structure of professional training in terms of the ratio of subject-specific, methodological, experimental, and digital components.

- 2) To conduct a comparative analysis of educational programs based on formalized indicators and to identify typological differences in approaches to ICT integration.

- 3) To compare the identified structural characteristics of educational programs with a proposed model of an interdisciplinary core for the training of future physics teachers.

Materials and methods. The empirical basis of the study consisted of 20 bachelor's degree programs in the B010 «Training of Physics Teachers» group, publicly available in the national register of educational programs (https://epvo.kz/#!/register/education_program). The analyzed programs are implemented by different higher education institutions in the Republic of Kazakhstan and correspond to innovative educational programs at Level 6 of the National Qualifications Framework.

The primary analytical material included the lists of academic disciplines forming the compulsory and elective components of each educational program. Where available, brief descriptions of course objectives and intended learning outcomes were also considered. Internal course syllabi, teaching materials, and instructional guidelines were deliberately excluded from the analysis. This limitation was introduced to ensure that the study focused on curriculum design decisions at the program level rather than on specific teaching practices.

The analysis was intentionally restricted to the titles of academic disciplines and their functional role within the structure of professional training. Such an approach made it possible to treat educational programs as integrated curricular constructs and to identify structural priorities embedded at the stage of program development.

The study employed an analytical research design combining semantic analysis with formalized quantitative data processing. This design was chosen to move beyond descriptive comparisons and to identify stable structural patterns related to the inclusion of digital technologies in physics teacher education.

The analysis was conducted in several successive stages.

Stage 1. Normalization and semantic analysis of discipline titles

At the first stage, all discipline titles across the 20 educational programs were normalized. Synonymous and partially overlapping formulations were consolidated in order to reduce terminological variability and to reveal recurring semantic structures. Subsequently, a semantic analysis was performed to identify key terms and markers indicating the functional orientation of the disciplines, such as references to experimentation, methodology, digital technologies, or research activity. This stage aimed to outline the dominant thematic areas shaping the structure of professional training for future physics teachers.

Stage 2. Formalized coding of disciplines

At the second stage, a binary content coding procedure was applied. Each discipline was assigned a set of indicators reflecting its primary functional orientation, including experimental, research, digital, and didactic components. Special attention was paid to identifying courses in which digital technologies were embedded in the context of teaching and learning processes rather than presented as an independent object of study. The coding results served as the basis for calculating relative indices characterizing the structural composition of each educational program.

Stage 3. Comparative and cluster analysis

At the next stage, educational programs were compared using the calculated indices. Cluster analysis was employed to identify typological differences between programs and to group them according to the degree of experimental, research, and digital orientation. Clustering was not intended to produce a rigid classification but was used as an analytical tool to detect recurring design patterns and to examine how digital components are positioned within the overall curriculum structure.

Stage 4. Interpretation and model comparison

At the final stage, the results of the quantitative and cluster analyses were interpreted from the perspective of preparing future physics teachers for the didactically grounded use of ICT. Particular attention was given to the relationships between subject-specific, methodological, experimental, and digital components of training and to the degree of their internal coherence within individual programs. The empirical findings were subsequently compared with the proposed model of an interdisciplinary core of physics teacher education in order to assess its correspondence with actual curriculum structures.

Data processing, statistical analysis and visualization were performed using Python libraries (pandas, scikit-learn, matplotlib) in a cloud-based computational environment.

The reliability of the study was ensured by the use of official and standardized data sources, the inclusion of all disciplines listed in the educational programs without selective sampling, and the application of uniform semantic and quantitative criteria across the entire dataset.

The main limitation of the study lies in its reliance on the declared content of educational programs, which does not allow for direct assessment of teaching practices or learning outcomes. Nevertheless, for the purpose of identifying structural trends and design priorities in physics teacher education programs, this methodological approach can be considered appropriate and sufficient.

Results and discussion. The empirical basis of the study consisted of discipline lists from 20 bachelor's degree programs in the «Physics Teacher Training» group. In total, 998 unique discipline titles were included in the analysis. The unit of analysis was an individual discipline.

To enable quantitative processing, a binary content coding procedure was applied. Each discipline was coded according to the presence or absence of five functional attributes: ICT didactic, digital tools, research methods, experimental focus, and STEM orientation. Coding was based exclusively on discipline titles and did not rely on external classification schemes.

On the basis of the coding results, four relative indices were calculated for each educational program: the ICT-Didactic Integration Index (IDII), the Digital Saturation Index (DSI), the Experimental Orientation Index (EOI), and the Research Index (RI). The use of relative indicators ensured comparability between programs with different total numbers of disciplines.

ICT-Didactic Integration Index (IDII) – proportion of disciplines with the ICT didactic attribute;

$$IDII = \frac{\text{The number of disciplines with the ICT didactic attribute}}{\text{The total number of disciplines in the educational programme}}$$

Digital Saturation Index (DSI) — proportion of disciplines classified as Digital Tools and STEM;

$$DSI = \frac{\text{The number of disciplines classified as Digital Tools and STEM}}{\text{The total number of disciplines in the educational programme}}$$

Experimental Orientation Index (EOI) — proportion of disciplines with an experimental focus;

$$EOI = \frac{\text{The number of disciplines with an experimental focus}}{\text{The total number of disciplines in the educational programme}}$$

Research Index — proportion of disciplines focused on research activities.

$$RI = \frac{\text{The number of disciplines focused on research activities}}{\text{The total number of disciplines in the educational programme}}$$

The use of relative indicators made it possible to correctly compare programs with a different total number of disciplines.

The calculated indices are presented in Table 1.

Table 1 – Integral indices characterizing the structure of bachelor-level physics teacher Educational programs

Educational programs (EP)	IDII	DSI	EOI	RI
EP 1	0,058	0.077	0.096	0.058
EP 2	0,045	0.068	0.115	0.077
EP 3	0,059	0.078	0.077	0.058
EP 4	0,098	0.137	0.096	0.038
EP 5	0,061	0.082	0.115	0.058
EP 6	0,02	0,060	0.134	0.077
EP 7	0,055	0.091	0.096	0.058
EP 8	0,075	0.094	0.096	0.077
EP 9	0,058	0.096	0.115	0.058
EP 10	0,054	0.071	0.096	0.038
EP 11	0,058	0.077	0.115	0.058
EP 12	0,054	0.077	0.096	0.077
EP 13	0,051	0.077	0.115	0.058
EP 14	0,058	0.096	0.134	0.098
EP 15	0,000	0.027	0.096	0.058
EP 16	0,058	0.074	0.115	0.077
EP 17	0,058	0.077	0.096	0.058
EP 18	0,057	0.094	0.115	0.058
EP 19	0,043	0.064	0.192	0.098
EP 20	0,069	0.116	0.096	0.038

Structural characteristics of educational programs

The data in Table 1 indicate noticeable differences in the structural composition of the analyzed educational programs. The Experimental Orientation Index demonstrates relatively stable values across most programs, ranging from 0.096 to 0.192, which reflects the traditionally strong role of laboratory and experimental training in physics teacher education. The share of research-oriented disciplines is moderate, with RI values varying from 0.038 to 0.098.

In contrast, the ICT-Didactic Integration Index shows consistently low values across almost all programs. Although non-zero IDII values are observed in 19 out of 20 educational programs, the index remains within a narrow range (0.020–0.098), indicating that disciplines explicitly focused on the didactically grounded use of digital technologies are represented only marginally. In most cases, such content is limited to one or two courses within the curriculum.

These results suggest that digital technologies are formally present in physics teacher education programs, but their didactic integration remains weak and structurally isolated from other components of professional training.

Figure 1 presents the distribution of the ICT-Didactic Integration Index across the analyzed educational programs.

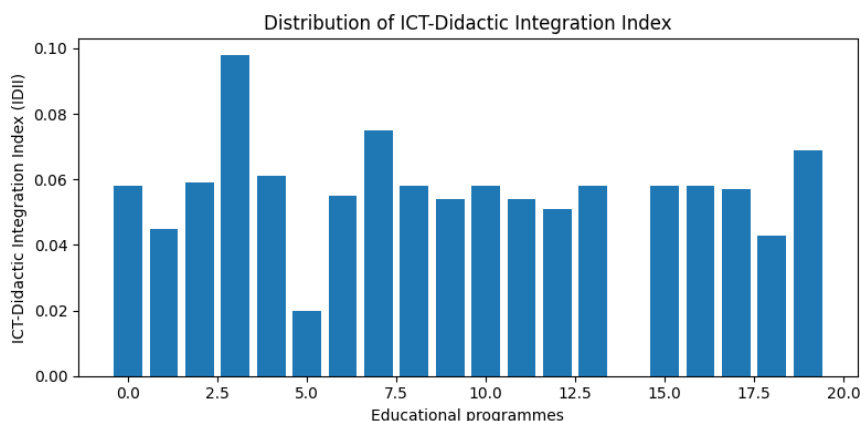


Figure 1 – Bar chart of ICT-Didactic Integration Index (IDII)

Note: The figure was created by the authors using Python data analysis tools

The results demonstrate that IDII values remain low and relatively homogeneous. None of the programs shows a pronounced level of didactically oriented ICT integration, which indicates the absence of systemic curricular emphasis on pedagogically meaningful use of digital technologies.

Figure 2 illustrates the average structural profile of physics teacher education programmes.

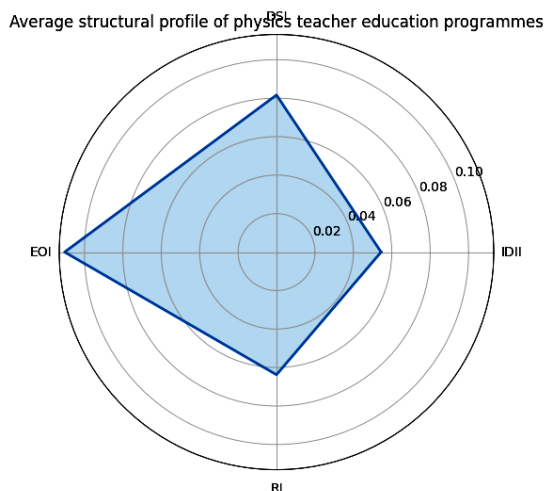


Figure 2 – Radar chart of the average structural profile

Note: The figure was created by the authors using Python data analysis tools

The radar chart clearly shows the dominance of experimental training, while the ICT-didactic component remains the least developed. This imbalance reflects a structural priority of experimental skills over pedagogically grounded digital integration.

Correlation analysis

To examine the relationships between didactic ICT integration and other structural components of educational programs, two hypotheses were tested:

H1. Educational programs with a stronger research orientation demonstrate a higher level of didactically grounded ICT integration.

H2. A higher experimental orientation of an educational program is associated with a higher level of didactic ICT integration.

Given the small sample size ($n = 20$) and the non-normal distribution of the indices, Spearman's rank correlation coefficient was used.

The analysis revealed no statistically significant correlation between IDII and the Research Index (Spearman's $\rho = -0.34$, $p = 0.144$). Similarly, the relationship between IDII and the Experimental Orientation Index was not statistically significant (Spearman's $\rho = -0.30$, $p = 0.201$).

These findings indicate that neither a strong experimental component nor an increased focus on research activities automatically leads to the didactically meaningful integration of digital technologies in physics teacher education programs.

Figure 3 presents the Spearman correlation matrix between the calculated indices.

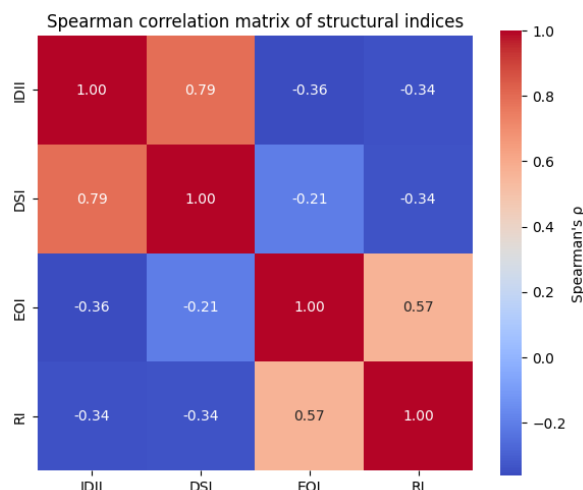


Figure 3 – Heatmap of Spearman correlations

Note: The figure was created by the authors using Python data analysis tools

The heatmap confirms the absence of statistically meaningful relationships between the ICT-Didactic Integration Index and other structural components. This indicates that the presence of experimental or research-oriented disciplines does not automatically lead to didactically meaningful use of digital technologies.

Cluster analysis

Based on four indices (IDII, DSI, EOI, RI), a cluster analysis was conducted using the k-means method. As a result, the educational programs were grouped into three clusters differing in the degree of experimental, research, and digital saturation.

To assess whether these typological differences were accompanied by differences in the level of didactic ICT integration, the Kruskal–Wallis test was applied. The results showed no statistically significant differences between clusters with respect to the ICT-Didactic Integration Index ($H = 0.43$, $p = 0.807$).

Figure 4 shows the results of k-means clustering based on the Digital Saturation Index and Experimental Orientation Index. The clustering reveals typological differences in program structure; however, these differences are not accompanied by systematic variation in ICT-didactic integration, confirming the instrumental nature of digitalization in the analyzed curricula.

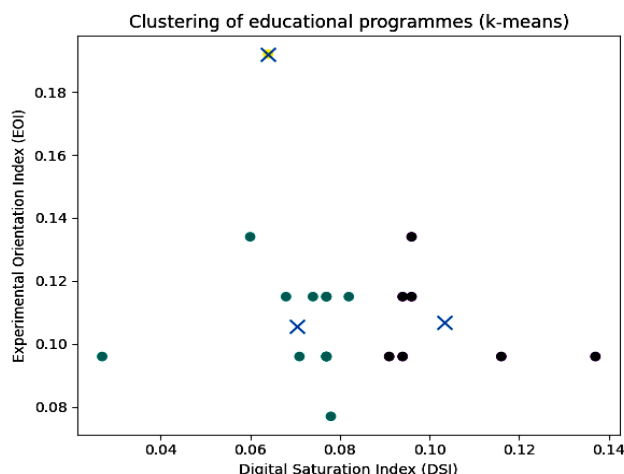


Figure 4 – Scatterplot with k-means clusters

Note: The figure was created by the authors using Python data analysis tools

The visual analysis confirms that digitalization in physics teacher education is structurally detached from both experimental and research components. Even in programs with strong experimental orientation, digital tools are not embedded into didactic decision-making or lesson design logic.

This outcome suggests that, although educational programs differ in their experimental and research orientation, these differences are not reflected in systematic variations in the didactically grounded use of digital technologies.

Taken together, the quantitative findings indicate that the digitalization of physics teacher education programs is predominantly instrumental in nature. Digital tools are introduced mainly through standalone or technically oriented courses and are rarely integrated into the methodological or experimental logic of professional training.

The absence of statistically significant correlations and intercluster differences in IDII points to a structural gap between experimental and research training, on the one hand, and the formation of competencies related to the didactically justified use of digital technologies, on the other. Even in programs with a strong experimental or research focus, digital tools are not systematically linked to lesson design, pedagogical decision-making, or the organization of educational experiments.

This structural gap provides empirical justification for the development of an interdisciplinary core of physics teacher education. Such a core should focus not on expanding the list of digital tools, but on their consistent integration into subject-specific methodology, experimental training, and pedagogical design. The proposed model of the interdisciplinary core (Figure 5) reflects this shift from fragmentary inclusion of digital disciplines toward a more coherent and interconnected curriculum structure.

Conclusion. This study analyzed bachelor's degree programs for the training of physics teachers with respect to the representation and structural role of information and communication technologies. Based on the formalized analysis of discipline lists from 20 educational programs, several conclusions can be drawn.

First, the analysis of curriculum structures showed that experimental and research components are consistently represented in physics teacher education programs. The values of the Experimental Orientation Index and the Research Index demonstrate moderate variability across programs, indicating a stable emphasis on laboratory work and research-oriented training. At the same time, disciplines explicitly focused on the didactically grounded use of digital technologies occupy a marginal position in the curricula. The ICT-Didactic Integration Index remains low in almost all programs and varies within a narrow range, which points to a limited and isolated inclusion of such content.

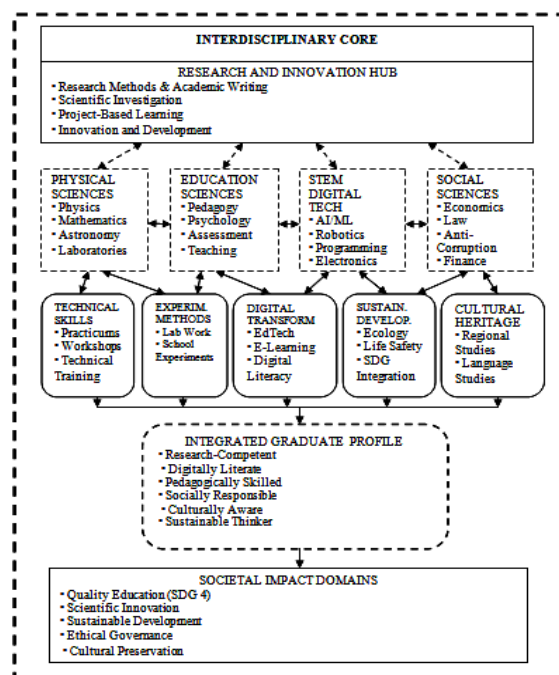


Figure 5 – The Model Of The Interdisciplinary Core Of Training Future Physics Teachers

Second, the comparative analysis based on correlation and cluster methods revealed that a higher experimental or research orientation of an educational program does not lead to a higher level of didactic ICT integration. Neither statistically significant correlations between the ICT-Didactic Integration Index and other structural indices nor significant intercluster differences were identified. This result indicates the existence of a structural gap between experimental and research training, on the one hand, and the formation of competencies related to the pedagogically meaningful use of digital technologies, on the other.

Third, the comparison of empirical findings with the proposed model of an interdisciplinary core of physics teacher education confirms the relevance of this model. The results show that digital technologies are predominantly introduced as standalone or instrumentally oriented elements and are weakly connected to subject methodology and experimental training. This supports the need for a curriculum structure in which digital tools are systematically integrated into lesson design, teaching methods, and educational experiments rather than added as isolated courses.

The main limitation of the study lies in its focus on the declared structure of educational programs, which does not allow conclusions to be drawn about actual teaching practices or learning outcomes. Future research may address this limitation by analyzing the implementation of curricula and assessing the development of ICT-related pedagogical competencies among pre-service physics teachers.

Overall, the findings highlight that the challenge in physics teacher education is not the availability of digital technologies, but their didactic integration into professional training. Addressing this challenge requires a shift from fragmentary digitalization toward a coherent interdisciplinary approach grounded in subject methodology and experimental practice.

Funding information. This research has been funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP22683901).

Conflict of interest: The authors declare no conflict of interest.

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Received: 03 May 2026. **Accepted:** 05 June 2026. **Published:** 30 September 2026.

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IRSTI 14.35.07

UDC 378.1

<https://doi.org/10.52269/SEPT2632076>

EXPLORING ENVIRONMENTAL EDUCATION AMONG UNIVERSITY STUDENTS IN KAZAKHSTAN AND TAJIKISTAN: FINDINGS FROM A PILOT STUDY

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The article examines university students' perceptions and experiences of environmental education in Kazakhstan and Tajikistan based on a pilot study. The relevance of the study is driven by global environmental