level of interest with signs of cognitive overload and an increase in the demand for practical skills. The theoretical significance of the work lies in clarifying approaches to understanding the role of AI in the educational process and substantiating the need for its integration on the basis of pedagogical expediency, ethics and responsibility. The practical significance of the study lies in the possibility of using its results to develop advanced training programs for teaching staff, improving the content of postgraduate education, and creating methodological recommendations for the effective use of AI in teaching. Prospects for further research are related to the development of models for the systemic integration of AI into the educational process, the creation of practical recommendations for teachers of various educational fields, comparing data with other regions of Ukraine, and studying the impact of AI on the learning outcomes of education seekers.

Keywords: *artificial intelligence; National Higher Education Institution; digital competence; postgraduate education; natural sciences; language and literature; academic integrity.*

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Project-research approach in shaping the digital culture of future teachers of the natural science and mathematics cycle

Abstract. *The article provides a theoretical and methodological substantiation of the project-research approach as a means of shaping the digital culture of future teachers of the natural science and mathematics cycle. The relevance of the study is determined by the need to overcome the fragmentation of teacher training, in which digital tools are often taught separately from subject methodology, assessment, and pedagogical decision-making. The author argues that the digital culture of a future teacher should be understood not as a set of isolated technical skills, but as an integrated professional quality manifested in the ability to design pedagogically meaningful digital solutions, work with educational evidence, interpret learning data responsibly, and continuously improve teaching practices. The study relies* *on theoretical analysis and synthesis of scientific sources, comparison of approaches, conceptual modeling, and generalization of methodological solutions relevant to STEM teacher education. The proposed framework integrates the logic of project-based learning, inquiry-based learning, TPACK, data literacy, and the ethical dimension of digital pedagogy. It is shown that the project-research cycle includes the following interrelated stages: formulation of a didactic problem, design of a digitally enriched solution, evidence planning, implementation, data analysis, and reflective redesign. Each stage is associated with specific artifacts, types of evidence, and quality criteria, which makes the process reproducible and pedagogically manageable. Particular attention is paid to scaffolding, assessment, ethical responsibility, and the methodological alignment of goals, content, methods, technologies, and evaluation. The article also proposes a typology of productive project formats for future science and mathematics teachers, including digital experiments, modeling projects, open data projects, integrated STEM cases, and digital assessment projects. It is concluded that the project-research approach enables the transition from learning digital tools to developing evidence-based, reflective, and ethically grounded professional practice.*

Keywords: *digital culture, digital competence, future teachers, project-research approach, STEM teacher education, TPACK.*

Introduction. The digital transformation of education over the past decade has significantly changed the requirements for the professional activity of a teacher, in particular in the field of natural and mathematical disciplines, where the educational content is organically connected with modeling, experiment, data processing, visualization of results and evidentiary argumentation (OECD, 2025a; Kharchenko et al., 2024). In modern schools, digital tools are increasingly acting not as an addition to learning, but as an environment for constructing knowledge: from digital laboratories and simulations to digital assessment and working with evidence of educational activity. In this context, the training of a future teacher requires not only mastering individual services or programs, but also the development of an integrated ability to select, apply and critically evaluate digital solutions in accordance with the didactic goal, context and needs of students (Redecker, 2017; OECD, 2025).

At the same time, a number of contradictions remain in the practice of training future teachers of the natural and mathematical cycle. On the one hand, teachers' digital competence is described in recognized frameworks that emphasize the need for systematic integration of digital resources into teaching, assessment, learning support and the development of students' digital literacy (Redecker, 2017). On the other hand, university training is often fragmented: digital practices are "separated" from the methodology of teaching specific subjects and are reduced to the acquisition of tools, while real pedagogical activity requires an integrated solution of "target-content-method-technology-assessment". This integration should be understood through the lens of TPACK, which conceptualizes the interdependence of technological, pedagogical and subject knowledge in the activity of a teacher (Mishra & Koehler, 2006).

Additionally, challenges related to academic integrity, copyright, protection of personal data, reliability of digital content and the need to form a culture of working with information and data in students are becoming more acute. In particular, the growing role of evidence in education reinforces the importance of a teacher's "data literacy" – the ability to interpret learning data and use it ethically and responsibly to make pedagogical decisions (Mandinach, 2016). At the same time, the spread of artificial intelligence tools raises the issue of ethical and pedagogically balanced use of digital technologies in the work of a teacher and in the training of future teachers (UNESCO, 2024). Recent evidence from STEM education also shows that teachers perceive AI as potentially valuable for supporting complex content learning and responsive instruction, yet they report major barriers such as insufficient institutional support, tool overload, and the need for structured, discipline-specific professional development (Avci et al., 2025).

All this reinforces the need for a theoretical and methodological understanding of effective approaches to the development of the digital culture of future teachers of natural and mathematical disciplines.

A promising approach in this context is the project-research approach, which combines the logic of educational design (creation of a pedagogically significant digital product) with the logic of research (statement of the problem, formulation of a hypothesis/pedagogical assumption, data collection, analysis of results, reflexive generalization). Project-based learning in pedagogical and general education is justified as an approach that contributes to the development of complex skills of the 21st century and the transfer of educational actions to real-world contexts of problem solving (Bell, 2010; Nalyvaiko, 2021). The research component is methodologically particularly relevant for the natural science and mathematics cycle, and empirical generalizations of the results of inquiry-based approaches in teaching natural sciences demonstrate the connection between qualitatively organized research (with an appropriate level of pedagogical support) and student learning outcomes (Furtak et al., 2012). In contrast to approaches focused mainly on training digital skills, the project-based organization of training allows transferring students' digital activity to the plane of professional pedagogical decisions and forming practices of methodologically appropriate, responsible and evidence-based use of technologies (Nalyvaiko, 2021).

In contemporary educational research, the concept of digital culture extends beyond the notion of digital competence and encompasses a broader system of professional values, practices, and ways of thinking related to the use of digital technologies. While digital competence is commonly defined as a set of knowledge, skills, and attitudes necessary for effective and critical use of digital tools (Redecker, 2017), digital culture reflects a more integrated and holistic professional quality.

Recent studies emphasize that digital culture includes not only technical proficiency, but also the ability to embed digital technologies into pedagogical design, to critically evaluate digital environments, to act ethically in data-rich contexts, and to continuously improve professional practice through reflection (Falloon, 2020; Huwer et al., 2025). In this sense, digital culture is closely connected with data literacy, ethical responsibility, and pedagogical reasoning.

Within the framework of this study, digital culture of future teachers of the natural science and mathematics cycle is understood as an integrated professional characteristic that includes the following interrelated components:

- digital literacy as the ability to use digital tools effectively;
- data literacy as the ability to interpret and use educational data;
- pedagogical integration of technologies in accordance with TPACK logic;
- ethical and responsible use of digital resources, including issues of privacy, academic integrity, and AI;
- reflective practice aimed at continuous improvement of teaching.

Thus, unlike digital competence, which focuses on “what a teacher can do with technologies”, digital culture emphasizes “how and why technologies are used in pedagogical decision-making and professional development”.

Thus, the relevance of the stated topic is determined by the need for pedagogical education in scientifically based methodological solutions that ensure the development of the digital culture of the future teacher of the natural science and mathematics cycle as a systemic professional quality. The article offers a theoretical and methodological analysis of the project-research approach and its potential for integrating digital technologies with subject methodology, work with data and reflective evaluation of the results of educational activities.

Despite the significant body of research on digital competence (Redecker, 2017), project-based learning (Bell, 2010), and inquiry-based approaches (Furtak et al., 2012), these areas are often addressed separately in both theoretical and practical contexts. Existing studies tend to focus either on the development of digital skills, or on pedagogical design, or on research-based learning, without offering an integrated framework that combines these dimensions into a coherent model of professional teacher training.

This fragmentation creates a significant research gap in understanding how digital technologies can function not only as tools but as integral components of pedagogical thinking and evidence-based decision-making. In particular, there is a lack of methodological models that simultaneously integrate project-based design, inquiry-based evidence generation, data literacy, and ethical considerations within the preparation of future teachers of the natural science and mathematics cycle.

This study addresses this gap by proposing a project-research approach that integrates design and evidence, supporting the development of digital culture as a holistic professional quality.

The purpose of the article is to provide a theoretical and methodological justification for the project-research approach as a way of forming the digital culture of future teachers of the natural science and mathematics cycle and to outline the methodological parameters of its implementation in the training of future teachers.

Methods: theoretical analysis and synthesis of scientific sources; comparison of approaches; conceptual modeling (allocation of stages of the project-research cycle and expected results); generalization of methodological solutions relevant to the training of future teachers of the science and mathematics cycle.

Methodological guidelines. The study is of a theoretical and methodological nature and is based on:

✔ a competency-based approach to the training of future teachers and framework guidelines for the digital competence of teachers (in particular, DigCompEdu), where digital technologies are considered in connection with teaching, assessment, and professional interaction;

✔ the integrative logic of TPACK, which explains why digital solutions in teacher training "work" should not separately, but in connection with subject content and methodology;

✔ project-based learning (PBL) as an approach that orients training towards the creation of a meaningful product and authentic educational situations;

✔ inquiry-based learning, the effectiveness of which in science education has been confirmed by generalizations of experimental and quasi-experimental research, provided that there is an appropriate level of pedagogical support (i.e., "guided" research activity).

✔ the data literacy approach, which emphasizes the importance of a teacher's ability to work with learning data to make informed decisions and use evidence responsibly;

✔ the ethical and normative dimension of a teacher's digital activity, which is strengthened in the context of the spread of AI and requires the systematic inclusion of ethical, pedagogical, and security aspects in the training of future teachers.

To ensure the methodological rigor of the study, particular attention was paid to the systematic selection and analysis of scientific sources. The literature review was conducted using the following criteria: relevance to the topic of digital pedagogy and teacher education; inclusion of recent studies (primarily from the last 7-10 years); and representation of key theoretical frameworks such as TPACK, data literacy, and inquiry-based learning.

Conceptual modeling was employed as the main methodological tool to construct the project-research cycle. The validity of the proposed model is ensured through its alignment with established theoretical frameworks (TPACK, DigCompEdu, inquiry-based learning) and through internal logical consistency between its components (problem → design → evidence → analysis → reflection).

Reliability in this theoretical study is achieved through triangulation of sources and approaches, including comparative analysis of different pedagogical models and synthesis of empirical findings reported in prior research. In addition, the reproducibility of the model is supported by the clear definition of stages, artifacts, and evaluation criteria, which allows its application in different educational contexts.

Theoretical foundations of the project-based research approach

In the modern discourse of teacher education, the project-based research approach should be interpreted not as a mechanical "combination of two methods", but as an integrated logic of professional training, within which the future teacher learns to act simultaneously in two modes: the design mode (creation of a pedagogically significant product) and the evidentiary research mode (substantiation of a pedagogical solution with data and arguments). Such an approach naturally corresponds to the epistemology of natural and mathematical disciplines, where knowledge appears not "as a sum of facts", but as the result of modeling, experiment, data analysis and reasoned conclusion.

The theoretical basis of the project-based research approach is formed by two related, but methodologically different paradigms: project-based learning (PBL/PjBL) and inquiry-based learning (IBL). In the classic review by J. Thomas, PBL is described as a model of learning organization in which the problem/question becomes central, and the result is a product that has clear quality criteria and involves participant autonomy, collaboration, and public presentation (Thomas, 2000). In this sense, "projectivity" is not reduced to the production of an artifact; it means a change in the logic of learning from following instructions to independently constructing a solution within the framework of a defined problem. At the same time, the empirically substantiated thesis of PBL is that high student activity does not guarantee high quality learning: design principles are needed that maintain a balance between "doing" and "learning" (Blumenfeld et al., 1991).

In contrast, inquiry-based learning focuses attention on a different plane on the procedures for acquiring knowledge: asking questions, forming assumptions, selecting evidence, interpreting data, and arguing conclusions. A meta-analysis by E. Furtak et al. showed that the positive effects of inquiry approaches in science education are statistically confirmed primarily when the research is organized as a guided, structured activity, rather than as a "free search" (Furtak et al., 2012). That is why it is important to take into account the position of Hmelo-Silver, Duncan and Chinn in the methodological discussion: effective inquiry (as well as problem-based learning) is fundamentally based on scaffolding - intermediate checkpoints, examples, prompts, criteria and other forms of pedagogical support that guide thinking and reduce the risks of chaos or superficiality (Hmelo-Silver et al., 2007).

Thus, the project-research approach in the preparation of future teachers of the science and mathematics cycle appears as a didactic response to the methodological problem: how to ensure that digital technologies in students' educational activities perform not a decorative function, but the function of a tool for pedagogical thinking and evidence-based solutions. It is fundamentally important here that for a teacher, "digital action" must always have a methodological justification: technology is relevant only when it supports a specific didactic goal, is consistent with the content of the subject and teaching methods, and is integrated into the system of assessment of results. It is this integrativity that is explained by the TPACK framework, which describes the professional knowledge of a teacher as an interconnected configuration of technological, pedagogical, and subject knowledge (Mishra & Koehler, 2006). In the context of STEM teacher training, TPACK is a particularly productive theoretical "lens" because it allows us to describe not the fact of using a digital tool, but the logic of its pedagogical feasibility.

Within the framework of this article, we understand the project-research approach as a methodically organized educational activity in which future teachers of the natural science and mathematics cycle:

- design and create a digitally enriched didactic product (lesson/module/series of tasks/simulation/digital experiment),
- justify pedagogical assumptions through evidence planning, data collection and analysis,
- carry out a reflexive generalization of the adopted technological and methodological decisions from the standpoint of feasibility, validity, and responsibility.

This definition allows us to conceptually "pull together" into a single construct what is often separated in traditional practice: the creation of a digital resource (project) and the verification of its pedagogical effectiveness or adequacy (research).

From a methodological point of view, only the project format creates the risk of reducing digital culture to "productivity": the digital resource is produced, but the pedagogical logic of its use and the demonstrability of the effect remain unclear (Soia et al., 2024; Kozlitin et al., 2020). This is the problem that Blumenfeld et al. emphasize, emphasizing the need to support learning, not just activity (Blumenfeld et al., 1991). Instead, only inquiry without productive output into a pedagogical product can reduce the professional authenticity of teacher training: research procedures are "detached" from the real task of the teacher designing a lesson, organizing educational interaction and assessing educational achievements. In this sense, the integration of PjBL + IBL has a double effect: it maintains a practical focus (through the product) and evidence (through research), while maintaining the manageability of the process (Furtak et al., 2012; Hmelo-Silver et al., 2007).

Summarizing the above, the project-research cycle in the preparation of a future teacher of the science and mathematics cycle can be logically described as a sequence in which design and research mutually reinforce each other: formulation of a didactic problem – design of a digitally enriched solution – planning of evidence – testing –data analysis and conclusions – reflective refinement of the product. It is this logic that creates the basis for the transition from theoretical justification to a description of how exactly (through which educational actions and artifacts) the digital culture of a future STEM teacher is formed (fig.1).

Fig. 1. “Structural model of the project-research approach: integration of PjBL and IBL in the training of future teachers of the natural and mathematical cycle
*Note. This figure was generated with the assistance of ChatGPT’s image generation tool (OpenAI) and further adapted by the author for the purposes of this study.

In the professional training of future teachers of the science and mathematics cycle, digital culture is not formed as a “superstructure” on top of digital literacy, but appears as a quality of pedagogical thinking and action, which is manifested in the ability to methodically justify technological solutions, work with evidence of learning, adhere to the ethical norms of the digital environment and reflexively improve one’s own practices. This view is consistent with the DigCompEdu framework logic, where a teacher’s digital competence is described through professional interaction, work with digital resources, organization of learning, assessment and development of students’ digital competence (Redecker, 2017). At the same time, for science and mathematics education, the inclusion of an evidential component becomes fundamental: digital technologies should support not only the “presentation of material”, but also the research logic of the subject - modeling, experiment, data analysis and substantiated conclusions (Furtak et al., 2012).

The project-research approach is methodologically productive precisely because it organizes the student’s activities in such a way that digital actions acquire professional meaning: each step of the project implies an expected pedagogical result and a requirement for evidence. At the level of methodological construction, this means that digital culture is formed not through “studying technologies”, but through a sequence of educational actions in which technology serves as a means of pedagogical design and research cognition. Such logic directly corresponds to the integrative framework of TPACK, which explains why the effective use of technology in teaching is possible only in connection with pedagogical strategies and subject content (Mishra & Koehler, 2006). In other words, the digital culture of a future teacher is manifested in the ability to keep in mind not the tool, but the didactic goal, and to choose technology as the optimal means of achieving it.

The first action that sets the quality of the entire subsequent project-research trajectory is the formulation of a didactic problem and the formulation of a pedagogical assumption. It is here that the fundamental "demarcation" of digital culture from instrumentalism occurs: the student does not start with the question "which service to use?", but proceeds from the question "what learning difficulty/deficit needs to be overcome and why is the digital approach methodologically justified?". In TPACK terms, this means that technological choice is subordinated to subject logic and pedagogical strategy (Mishra & Koehler, 2006). At this stage, digital culture manifests itself as the ability to define a goal, describe expected results, and outline the success criteria of a future digital solution.

The second key action is the design of a digitally enriched solution (lesson, module, simulation, digital experiment, assessment system). In PBL logic, it is important that the product should not be an "artifact for the sake of an artifact", but a pedagogically meaningful result for which quality criteria are defined (Thomas, 2000). That is why digital culture at this stage manifests itself as the ability to justify: (a) why the chosen digital format is adequate for the purpose; (b) what pedagogical methods support learning in digital interaction; (c) how the accessibility, transparency and repeatability of the solution are ensured.

It is important to emphasize that the quality of project design is directly related to "supporting learning", and not only to the activity of implementation. The classic study of motivation in PBL emphasized that successful project environments require structured intermediate goals, criterion-based assessment and support for thought processes, otherwise "doing" dominates over "learning" (Blumenfeld et al., 1991). In the preparation of a future teacher, this takes on additional importance: designing a digital lesson should be not only creative, but also didactically disciplined.

The third action that fundamentally strengthens digital culture is planning evidence and organizing data collection. It is here that the project-research approach "turns on" the research logic: the student must determine what data can confirm or refute his pedagogical assumption, with what tools this data will be collected and how it will be interpreted. The concept of data literacy for the teacher in this context is not a technical skill, but a professional competence that includes knowledge, attitudes and the ability to work with data as a basis for decision-making (Mandinach, 2016; Reeves, Summers & Grove, 2016). Accordingly, digital culture here manifests itself as the ability to transform digital traces of learning (test results, rubrics, activity artifacts, observations) into pedagogically meaningful conclusions (fig. 2).

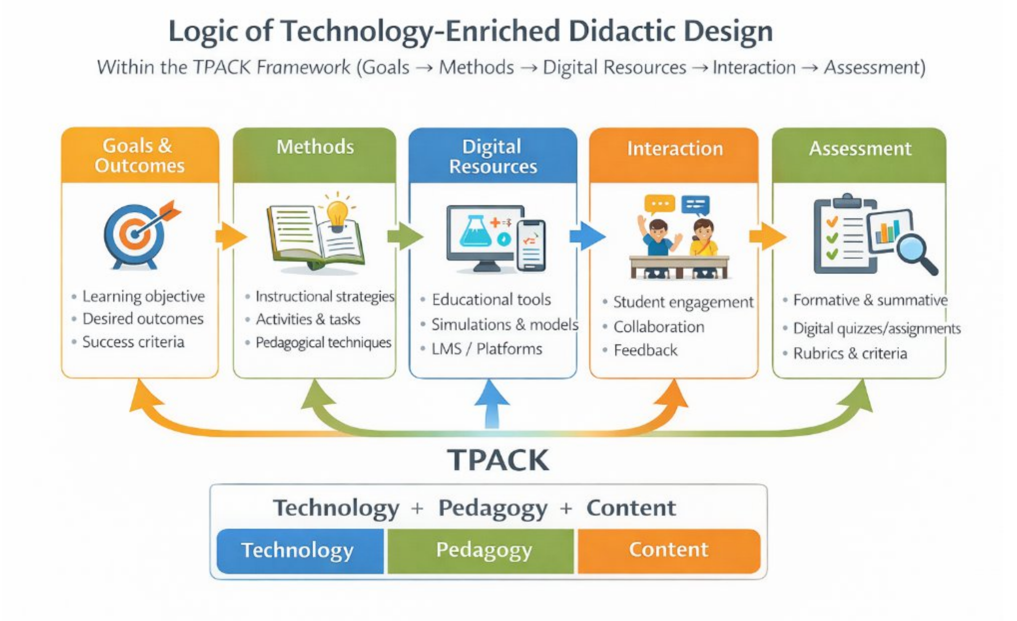

Fig. 2. “The logic of digitally enriched instructional design within TPACK. *Note. This figure was generated with the assistance of ChatGPT’s image generation tool (OpenAI) and further adapted by the author for the purposes of this study.

This stage is also directly related to ethical issues: data collection requires consideration of privacy, transparency of procedures and responsible use of information. Modern frameworks for teacher competences in the context of AI emphasize the need to understand ethical risks and work safely with data (UNESCO, 2024). The evidence plan is therefore both a methodological and ethical step in digital culture. At the stage of testing and analysis of the results, the key requirement for inquiry-logic is manifested - controllability and methodical organization of the study. Meta-analysis by E. Furtak et al. showed that inquiry-based approaches give the best results when the activities of participants are accompanied by pedagogical supports (Furtak et al., 2012). This position is supported by the arguments of Hmelo-Silver and colleagues, who emphasize the role of scaffolding as a condition for achieving learning outcomes in problem-based and inquiry learning (Hmelo-Silver et al., 2007). In the preparation of a future teacher, this conclusion has a double value: first, it teaches the student to organize his own research methodically, and secondly, it forms the readiness in the future to ensure the controllability of students' research.

Digital culture here manifests itself in the ability to: (a) correctly interpret data; (b) distinguish “fact” from “explanation”; (c) recognize data limitations; (d) draw conclusions relevant to teaching methodology. In natural sciences and mathematics, this directly corresponds to the logic of subject knowledge: demonstrability, reproducibility, and validity. The final action, reflective refinement of the product, is fundamentally important because it translates the results of the analysis into professional improvement. This is the moment when digital culture ceases to be a “one-time success” and becomes a sustainable practice: the student not only records what "worked/did not work", but also formulates which design elements need to be revised, how the logic of the lesson changes, which digital resources need to be clarified, and which ethical aspects need correction. In DigCompEdu terms, this correlates with the idea of continuous professional development in the digital sphere and the reflective use of technology in pedagogical activity (Redecker, 2017). Thus, reflection completes the cycle, but at the same time opens the next iteration and it is precisely "interactivity" that is one of the basic characteristics of digital culture in the teaching profession (fig.3).

Fig. 3. Iterative Design–Evidence–Improvement Model for Developing the Digital Culture of Future Teachers of the Natural Science and Mathematics Cycle. *Note. This figure was generated with the assistance of ChatGPT's image generation tool (OpenAI) and further adapted by the author for the purposes of this study.

The presented logic in this sequence "action, result, manifestation of digital culture" sets the methodological basis for further description of how the project-research cycle should be organized in the training of a future teacher of the natural science and mathematics cycle (principles, stages, results, types of projects). It is this aspect of methodological design – that allows us to translate theoretical principles into a system of reproducible educational solutions.

The transition from the theoretical justification of the project-research approach to its methodological implementation requires that the cycle be described as a reproducible pedagogical procedure, and not as a set of "successful practices". In this context, methodological design serves as a tool for organizing educational activities: it sets the logic of sequential steps, defines expected artifacts (products), fixes types of evidence and creates conditions for the controllability of cognitive processes (scaffolding), which is fundamentally important for PBL and inquiry-based learning (Thomas, 2000; Hmelo-Silver et al., 2007). At the same time, for the science and mathematics cycle, methodological design should maintain a dual focus: (a) the pedagogical feasibility of the digital solution (integration of “meta-content-method-technology-assessment” in the TPACK logic), and (b) the evidence-based judgments about the results (data literacy as the basis for data analysis and interpretation) (Mishra & Koehler, 2006; Mandinach, 2016).

Methodologically, it is important to assume that in a project-based approach, students do not simply “perform tasks” but model the activity of a teacher as a professional who makes decisions in conditions of complexity and limited resources. Therefore, the design should include not only the formulation of the problem and the creation of a product, but also a system of mandatory explanations (rationales): why the goal is formulated in this way, why specific methods and digital resources are chosen, how the correspondence of the content and students’ activities to the expected results is ensured. This principle is consistent with the idea of “supporting learning, not just activity”, which is consistently emphasized in PBL research (Blumenfeld et al., 1991). From the standpoint of TPACK, it is the argumentation of the connection between technology, pedagogy and content that turns the use of digital tools into a meaningful professional action (Mishra & Koehler, 2006).

From a methodological point of view, it is advisable to present the project-research cycle as a sequence in which each stage ends with an artifact that is subject to expert assessment and micro-evidence that confirms the adequacy of the decision made. It is this phasing that ensures manageability and reduces the risk that the project will turn into “product manufacturing” and the research into a formality. The characteristics of a “quality project” consistent with scientific PBL reviews (problem centrality, autonomy, quality criteria, publicity of the result) should be methodically “decomposed” into checkpoints that are understandable to the student (Thomas, 2000). Similarly, “qualitative inquiry” requires structures and support that guide the work with data and the argumentation of conclusions (Hmelo-Silver et al., 2007; Furtak et al., 2012).

To make the cycle methodically manageable, it is advisable to incorporate typical scaffolding elements: a problem formulation template; a TPACK compliance checklist (the question “is the technology aligned with the methods and content?”); a proof plan template; examples of correct conclusions; an assessment rubric with descriptors. This support logic is directly consistent with the position that effective inquiry/problem-based learning involves thoughtful pedagogical support, rather than minimal management (Hmelo-Silver et al., 2007). At the same time, scaffolding in PBL helps maintain a balance between product creation and learning outcomes (Blumenfeld et al., 1991).

Table 1.

Methodological design of the project-research cycle

Stage of the project and research cycle	**Key actions of the applicant (future teacher)**	**Required artifacts (products/documents)**	**Data/evidence**	**Quality criteria (for peer review/rubric)**
1. Problem	• Identifies the	1) Problem	• Diagnostic	• Clarity and validity of

Stage of the project and research cycle	Key actions of the applicant (future teacher)	Required artifacts (products/documents)	Data/evidence	Quality criteria (for peer review/rubric)
framing (statement of a didactic problem)	didactic problem/difficulty of students in a specific topic of the science and mathematics cycle. • Formulates a pedagogical assumption (hypothesis) regarding a digitally enriched solution. • Identifies expected learning outcomes and success criteria.	passport (brief description, context, target group). 2) Pedagogical assumption. 3) Expected learning outcomes (LO) + success criteria. 4) Justification of the relevance of the digital approach.	data (preliminary results, typical errors). • Observation /analysis of learning artifacts (student work, answers). • Short results of the input assessment (pre-test / quick check).	the problem statement. • Correspondence of the LO to the problem and age characteristics. • Justification of the digital approach (not “because it is interesting”, but “because it is methodically necessary”) • Operationality of success criteria.
2. Design (designing a digitally enriched solution)	• Designs a didactic scenario (lesson/module/cycle of classes). • Determines methods/forms of work, student activities, and the teacher's role. • Selects digital resources and describes their function in learning. • Ensures consistency of “goals → methods → resources → interaction → assessment” (TPACK logic).	1) Lesson plan/lesson/module outline. 2) Description of digital resources (links/screenshots/instructions). 3) Didactic rationale for resource selection (rationale). 4) Student materials (instructions, templates, tasks).	• Project documentation (design versions). • TPACK compliance expert checklist (self-assessment + external assessment). • Fragments of student instructions as evidence of accessibility and understandability.	• Methodological feasibility (consistency of purpose, content, methods and technologies) (Mishra & Koehler, 2006). • Quality of project design (criteria/intermediate goals/structure) (Blumenfeld et al., 1991). • Accessibility and clarity of materials. •Realistic implementation in the school context.
3. Evidence plan (evidence plan and preparation of data collection tools)	• Determines indicators of LO achievement. • Selects data collection methods (rubric, test, checklist, artifact analysis, activity log). • Designs assessment tools (formative and summative). • Plans data analysis algorithm and interpretation criteria. • Considers ethical requirements	1) Matrix “LO → indicator → tool → data”. 2) Rubric/assessment criteria. 3) Diagnostic tasks (pre/post). 4) Observation checklist/artifact analysis protocol. 5) Data analysis plan + ethical protocol.	• Pilot results of the tools (understandability check). • Examples of completed rubrics (mock data). • Description of the data collection and storage procedure (privacy).	• Validity of indicators and compliance with LO (Mandinach, 2016). • Reliability of instruments (clear descriptors, minimization of subjectivity). • Transparency of the analysis algorithm. • Ethical correctness (UNESCO, 2024)

Stage of the project and research cycle	**Key actions of the applicant (future teacher)**	**Required artifacts (products/documents)**	**Data/evidence**	**Quality criteria (for peer review/rubric)**
	(privacy, consent, data minimization).			
4. Implementation (testing: microteaching/simulation/practice)	• Implements the scenario in microteaching format or in practice. • Ensures the process is manageable (instructions, time frames, student support). • Collects planned data. • Captures contextual factors (conditions, constraints, technical failures).	1) Microteaching recording/protocol (video/audio/observation notes). 2) Collected student work/artifacts (files, screenshots). 3) LMS/platform data (if available). 4) Implementation logbook + deviation notes.	• Results of task completion (formative/summative). • Observations (checklist). • Activity logs (time, participation, attempts). • Student/participant feedback (short questionnaire).	• Fidelity of design implementation (what is actually done) (Thomas, 2000). • Controllability of inquiry/learning process (scaffolding) (Hmelo-Silver et al., 2007). • Completeness and quality of data (sufficiency for conclusions). • Compliance with ethics during data collection (UNESCO, 2024).
5. Analysis (data analysis and reasoned conclusions)	• Cleans/structures data. • Performs analysis according to plan (descriptive statistics, pre/post comparisons, qualitative analysis of artifacts). • Interprets data in relation to LO and pedagogical assumptions. • Identifies limitations, alternative explanations, influencing factors.	1) Analytical report (structure: data → analysis → conclusions). 2) Visualizations (tables/charts). 3) Interpretation regarding LO (what is confirmed/not confirmed). 4) List of limitations and validity risks.	• Comparison of results (pre/post, groups, levels). • Distributions by rubric. • Examples of "before/after" artifacts. • Feedback snippets.	• Correctness of analysis (data literacy) (Mandinach, 2016). • Reasonability of conclusions (data → statements). • Consideration of limitations and context. • Consistency of conclusions with inquiry theory and PBL (Furtak et al., 2012).
6. Reflection & redesign (reflection, ethical audit, refinement)	• Reflects: what worked/didn't work and why. • Formulates decisions to refine the design based on data. • Performs ethical audits of digital practices (sources, copyright, privacy, transparency). • Plans the next iteration (what to change, what data to re-collect).	1) Reflective report (evidence-based). 2) Improvement plan (redesign plan). 3) Ethical checklist (integrity/copyright/data). 4) Updated product version (v2) + short description of changes.	• Comparison of versions (v1→v2). • Justification of changes (link to data). •Checking sources/licenses. • Self-assessment + peer-review comments.	Reflective validity (data → conclusions → changes). • Quality of refinement (purposefulness, minimization of redundancy). • Ethical responsibility (UNESCO, 2024). • Orientation to continuous professional development in the digital environment (Redecker, 2017).

Table 1 demonstrates that the design-research cycle is structured as a sequence of guided stages, each of which culminates in specific artifacts and a set of evidence sufficient to support pedagogical conclusions. This structure is consistent with research findings on the need to support learning in PBL (Blumenfeld et al., 1991) and on the effectiveness of guided inquiry (Furtak et al., 2012; Hmelo-Silver et al., 2007).

If the methodological design of the project-research cycle answers the question “how to organize the process”, then the typology of projects specifies “what exactly to do” within this process, so that digital technologies play not an auxiliary, but a constitutive role in teaching natural and mathematical disciplines. The fundamental requirement is that the digital component be connected with subject epistemology: measurement, modeling, experiment, data interpretation and reasoned substantiation of conclusions. That is why it is advisable to abandon “universal” digital projects, which can be implemented in any subject, and instead focus on projects where technology is a tool of scientific knowledge and pedagogical decision. This position is consistent, on the one hand, with the features of quality PBL (problem centrality, quality criteria, artifact as a result) (Thomas, 2000), and on the other hand, with the conclusions regarding the effectiveness of inquiry-based learning in the natural sciences, provided that it is manageable and structured (Furtak et al., 2012).

In the proposed typology, each type of project simultaneously acts as a “container” for the formation of key manifestations of digital culture: methodological expediency (TPACK-coherence), demonstrability (working with data), ethical responsibility, and reflective improvement. Below are the types of projects that are methodologically most productive for the natural science and mathematics cycle.

1. Digital Experiment and Virtual Laboratory Projects

This type of project is based on the fact that a significant part of the educational content of natural sciences involves working with cause-and-effect relationships, variables, measurements, and control of conditions. In a digitally enriched format, the student designs an educational experiment (or digital laboratory work), determines the variables and the procedure for recording the results, and also establishes mechanisms for checking students’ understanding and typical errors. Here, digital culture is manifested not in “using a simulator”, but in the ability to transform the simulation into a learning-guided research process with clear goals and evidence. It is the requirement for manageability that is critical, since the effectiveness of inquiry-based approaches depends on the quality of methodological support (Furtak et al., 2012; Hmelo-Silver et al., 2007).

Typical products (artifacts): lab instructions, digital experiment protocol, grading rubric, data interpretation task set, evidence package (student work, results). Key evidence: before/after comparisons of understanding of variables, correctness of interpretation of graphs/tables, quality of explanations.

2. Modeling projects (mathematical, physical, chemical, biological)

Modeling is a natural "language tool" of natural and mathematical knowledge, and digital technologies significantly expand the possibilities of modeling through parameterization, visualization, comparison of scenarios and rapid testing of hypotheses. Methodologically valuable is such a project design in which students do not just "look at the model", but interact with it: change parameters, record results, compare options, explain patterns. In this type of project, the digital culture of the future teacher is manifested in the integration of technology with subject logic and pedagogical methods, which corresponds to the TPACK framework (Mishra & Koehler, 2006).

Typical products: digital model/simulation with a description of parameters, a scenario of educational interaction, a set of "what if…" tasks, a rubric for explaining patterns, a plan for collecting evidence. Key evidence: quality of students' argumentation, correctness of conclusions from the model, ability to transfer modeling to real-world situations.

3. *Open data and educational analytics projects*

Data-driven projects are one of the most direct ways to build digital culture as evidence-based pedagogical quality. They allow you to combine subject-specific competencies (statistics, functions, patterns, causality) with the development of data literacy. For a future teacher, the key is not only the ability to "build a graph", but also the ability to build didactic logic: what question do we ask about the data, what data is relevant, how to avoid misinterpretations, how to teach students to argue conclusions (Reeves, Summers & Grove, 2016). This is the formulation that corresponds to the understanding of data literacy as a set of knowledge, skills and dispositions for making pedagogical decisions based on data (Mandinach, 2016).

Typical products: a data analysis task, table/visualization templates, interpretation instructions, argumentation evaluation criteria, evidence plan. Key evidence: correctness of interpretation, validity of conclusions, ability to distinguish correlation from causation (at a level accessible to the age), reflection on errors.

4. Integrated STEM/STEAM cases as projects of a comprehensive digitally enriched solution

Integrated cases are methodologically relevant when it is necessary to combine knowledge from several disciplines and direct it to solving a practical problem. At the same time, for the formation of a digital culture, it is fundamentally important that interdisciplinarity does not turn into superficial "collage". The features of high-quality PBL, a central question, quality criteria, a public product and a real problem allow you to maintain the discipline of thinking and responsibility for the result (Thomas, 2000). The research component (evidence plan, data, conclusions) ensures demonstrability and prevents formality. In this type of project, digital culture is formed as the ability to coordinate content, methods and digital resources in a comprehensive educational design, without losing the transparency of assessment and ethical requirements.

Typical products: project package (problem brief, solution design, prototype/resource, assessment tools, evidentiary report), presentation for defense. Key evidence: relevance of the solution to the problem, quality of argumentation, assessment results, reflection on team interaction.

5. Digital assessment and didactic diagnostics projects

Digital assessment is not only a technical tool, but a fundamental element of professional digital culture, as it provides a connection between goals, activities and results. In such projects, the student creates a task bank/rubric/formative assessment system, plans data collection, analyzes the results and adjusts the didactic design. This is where the logic of "design –evidence – improvement" is most evident (supported by your visualization of Figure 3). At the same time, digital assessment requires ethical and normative sensitivity: transparency of criteria, fairness, data privacy, correct use of digital tools - aspects that are amplified in the context of the spread of AI (UNESCO, 2024).

Typical products: rubric, task bank, instructions, analytical report on results, improvement plan. Key evidence: validity of tasks/rubrics, stability of assessment, validity of design correction.

The proposed typology allows us to see that different types of projects have a common methodological "matrix" (problem – design – evidence – analysis –improvement), but differ in the dominant subject mechanism (experiment, model, data, integration, evaluation). This allows us to plan the training of future teachers as a trajectory of complication: from a single microproject to a complex case, from basic evidence to more analytical forms of interpretation of results, which corresponds to the logic of guided inquiry and qualitative PBL (Furtak et al., 2012; Thomas, 2000).

In the context of research, it is very important to define the role of project evaluation. In the project-research approach, evaluation performs not only a control, but primarily a regulatory function: it "stitches" goals, design, evidence and improvement into a single professional trajectory. That is why it is not the creation of a digital product that is subject to evaluation, but rather the quality of the pedagogical solution, the validity of the evidence, and the responsibility of digital practices. This position is consistent with the classic conclusion of PBL research on the need to support "learning" alongside "doing" through criteria, intermediate checkpoints and structured feedback (Blumenfeld et al., 1991), as well as with the results of a meta-analysis on inquiry approaches, where effectiveness is related to the manageability and methodological quality of the evidence procedures (Furtak et al., 2012).

Recommended evidence package (minimum set for evaluation):

- digital product (lesson/module/simulation/assessment);
- rationale with TPACK logic (Mishra & Koehler, 2006);
- evidence plan and data collection tools;
- collected data/artifacts;
- analytical conclusion;

● reflective revision (Redesign) in the logic of “design – evidence – improvement”.

It is advisable to reduce the evaluation criteria to 4-5 “core” positions: (a) methodological feasibility, (b) research validity, (c) technological quality and accessibility, (d) ethics and integrity, (e) reflective improvement (Mandinach, 2016; UNESCO, 2024).

Discussion

The resulting theoretical and methodological construct allows us to consider the project-research approach as a coherent solution for the formation of the digital culture of future teachers of the science and mathematics cycle, since it removes the typical tension between “digital activity” and “methodological expediency”. The built-in requirement for evidence changes the nature of the student’s digital activity: technology ceases to be a presentation tool and becomes a tool for pedagogical thinking (TPACK) and pedagogical evidence (data literacy) (Mishra & Koehler, 2006; Mandinach, 2016). This is especially significant for science and mathematics disciplines, where the educational logic is close to the logic of scientific knowledge, and inquiry approaches, under conditions of control, demonstrate a positive relationship with learning outcomes (Furtak et al., 2012; Hmelo-Silver et al., 2007).

At the same time, the methodological effectiveness of the approach depends on two critical factors. First, on the quality of scaffolding: in the absence of clear templates, control points and criteria, the project is easily reduced to “making a product”, and the research part to a formal “verification” (Blumenfeld et al., 1991; Hmelo-Silver et al., 2007). Second, on the culture of evaluation: if only the product is evaluated, and not the logic of the evidence, then the approach loses its key advantage - professional demonstrability and reflexive improvement (Soia et al., 2024; Kozlitin et al., 2020). In addition, the importance of the ethical block is growing: digitalization and AI tools require from the future teacher sensitivity to privacy, copyright, integrity and transparency of procedures (UNESCO, 2024).

In conclusion, the project-based approach can be interpreted as a methodological mechanism that combines: the productivity of PBL; the evidence-based nature of guided inquiry; the integrative nature of TPACK; data literacy as a basis for pedagogical decision-making. It is this composition that allows us to transfer the formation of digital culture from the level of “learning tools” to the level of professional practice that can be substantiated, tested, and improved.

Conclusions

Thus, it can be concluded that within the framework of this study, the project-research approach is conceived as an integrated format for the professional training of future teachers of the natural science and mathematics cycle, in which digital technologies perform not an auxiliary, but a conceptually defining function: they become a means of didactic design, organization of educational interaction and evidence-based substantiation of pedagogical decisions. In such logic, the digital culture of a future teacher appears not as a set of individual digital skills, but as the quality of pedagogical thinking and action, which is manifested in the ability to see a didactic problem, select digital resources in accordance with the goals and content, build a methodically justified sequence of educational actions and ensure transparent evaluation of results.

The procedure of the project-research cycle proposed in the article ("problem formulation – design of a digitally enriched solution – evidence plan – testing – analysis – reflective refinement") allows structuring training as a reproducible process in which students' digital activity acquires professional meaning and moves into the plane of verifiable pedagogical conclusions. The methodological advantage of such a cycle lies in the combination of "product" and "evidence": a digital didactic product is considered as the result of design, while planning, data collection and analysis are considered as mechanisms for establishing pedagogical feasibility and clarifying the effectiveness of the proposed solution.

It is shown that for the natural science and mathematics cycle, the types of projects that reproduce the subject logic of scientific knowledge are particularly productive: digital experiment, modeling, work with open data, integrated STEM cases and digital assessment. It is these formats that enhance the evidence-based nature of educational actions and at the same time form in the future teacher sustainable practices of working with data, reasoning conclusions and reflective improvement of teaching design.

It is separately emphasized that the effectiveness of the project-research approach is determined not by the number of digital tools used, but by the quality of methodological design: the presence of clearly defined artifacts, control points, transparent criteria and evidence-based evaluation, which records not only the readiness of the product, but also the validity of pedagogical decisions, the validity of evidence and the ability to professional refinement. Thus, the project-research approach can be considered as a methodological mechanism that transfers the formation of the digital culture of the future teacher from the level of "mastery of tools" to the level of responsible, evidence-based and reflective professional practice.

The proposed project-research approach opens several promising directions for further research. First, empirical validation of the model in real educational settings is required to assess its effectiveness in shaping the digital culture of future teachers. Second, further studies may explore the integration of artificial intelligence tools into the project-research cycle and their impact on pedagogical decision-making and data interpretation. Third, longitudinal research is needed to examine how the development of digital culture evolves over time during teacher education and professional practice. Finally, it is promising to study the possibilities of adapting this approach to other educational fields beyond the natural science and mathematics cycle, particularly in interdisciplinary and humanitarian contexts.

AI Use Statement. Artificial intelligence was used only as an auxiliary tool in the preparation of this article. Specifically, AI-assisted image generation was used to create preliminary versions of several figures, which were subsequently revised, adapted, and conceptually validated by the author. AI tools may also have been used for limited language support during manuscript drafting. The author independently conducted the literature analysis, developed the theoretical framework, interpreted the findings, and took full responsibility for the content, scholarly validity, and final form of the article.

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Проєктно-дослідницький підхід у формуванні цифрової культури майбутніх учителів природничо-математичного циклу

Анотація. *У статті наведено теоретико-методичне обґрунтування проєктно-дослідницького підходу як засобу формування цифрової культури майбутніх учителів природничо-математичного циклу. Актуальність дослідження визначається необхідністю подолання фрагментації педагогічної підготовки, в якій цифрові інструменти часто викладаються окремо від методології предметів, оцінювання та прийняття педагогічних рішень. Автор стверджує, що цифрову культуру майбутнього учителя слід розуміти не як сукупність ізольованих технічних навичок, а як інтегровану професійну якість, що проявляється у здатності проектувати педагогічно значущі цифрові рішення, працювати з освітніми доказами, відповідально інтерпретувати навчальні дані та постійно вдосконалювати педагогічну практику. Дослідження спирається на теоретичний аналіз та синтез наукових джерел, порівняння підходів, концептуальне моделювання та узагальнення методологічних рішень, що стосуються STEM-освіти вчителів. Запропонована структура інтегрує логіку проєктного навчання, навчання* *на основі дослідницьких досліджень, TPACK, грамотність даних та етичний вимір цифрової педагогіки.*

Показано, що проєктно-дослідницький цикл включає такі взаємопов'язані етапи: формулювання дидактичної проблеми, проєктування цифрового збагаченого рішення, планування доказів, впровадження, аналіз даних та рефлексивний редизайн. Кожен етап пов'язаний зі специфічними артефактами, типами доказів та критеріями якості, що робить процес відтворюваним та педагогічно керованим. Особлива увага приділяється підготовці, оцінюванню, етичній відповідальності та методологічному узгодженню цілей, змісту, методів, технологій та оцінювання. У статті також пропонується типологія продуктивних форматів проєктів для майбутніх вчителів природничих наук та математики, включаючи цифрові експерименти, проєкти моделювання, проєкти відкритих даних, інтегровані STEM-кейси та проєкти цифрового оцінювання. Зроблено висновок, що проєктно-дослідницький підхід дозволяє перейти від вивчення цифрових інструментів до розвитку професійної практики, що базується на доказах, рефлексії та етичній обґрунтованості.

***Ключові слова**: цифрова культура, цифрова компетентність, майбутні вчителі, проєктно-дослідницький підхід, STEM освіта вчителів, TPACK.*

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ТЕОРІЯ І МЕТОДИКА ПРОФЕСІЙНОЇ ОСВІТИ

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Implementing an andragogical approach to foreign language training of adult military learners

***Abstract.** The article addresses the issue of enhancing foreign language communication training for future officers in higher military education institutions under conditions of ongoing war and intensified international*