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The development of digital skills in primary school pupils through the project-based activities of university students

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Introduction: Developing pupils' digital competence is a core goal of primary education, yet many schools lack scalable approaches that combine authentic tasks with consistent scaffolding. This study tested whether student-facilitated, scaffolded project-based learning (PBL) improves pupils' DigComp-aligned digital competence compared with standard instruction.

Methods: A quasi-experimental, non-equivalent control group pretest–posttest design was conducted in one mainstream public primary school in Kazakhstan with Grades 2–4 pupils (N = 124; experimental n = 62; control n = 62). The intervention comprised six scaffolded PBL modules delivered over one academic term (16 weeks) and supported by 24 trained teacher-education undergraduates acting as classroom facilitators under teacher and researcher supervision. Outcomes included a DigComp 2.1-informed performance diagnostic across four domains (information literacy; communication/collaboration; content creation; digital safety), a 5-point pupil self-assessment of digital confidence, and structured observations (Kendall's W = 0.84). Between-group differences were tested using independent-samples t-tests (Welch's t where appropriate) and reported with Cohen's d.

Results: Groups were comparable at pretest on the overall index (2.47 $\pm$ 0.52 vs. 2.49 $\pm$ 0.55; p = 0.857). At posttest, the experimental group outperformed the control group on overall digital competence (3.85 $\pm$ 0.44 vs. 3.08 $\pm$ 0.51; t = 7.11; $p < 0.001$; d = 1.10) and across domains (d = 0.52–1.34). Digital confidence increased more strongly in the experimental group (Δ = 1.42 vs. 0.54; t = 6.95; $p < 0.001$; d = 1.25).

Discussion: Student-facilitated, scaffolded PBL was associated with meaningful gains in primary pupils' digital competence and confidence over one term. The findings suggest a feasible university–school partnership model for supporting early-grade digital skills development, although evidence is currently limited to a single-school context.

KEYWORDS
DigComp 2.1, digital competence, Kazakhstan, primary school pupils, project-based learning, quasi-experimental design, university student facilitators

Introduction

Modern education systems are increasingly confronted with the need to deliberately cultivate digital skills in primary school pupils. Early acquisition of basic digital competence not only contributes to academic success in later stages of education but also lays the foundation for a child's social integration in a digitally mediated society. Researchers identify early school age as a particularly sensitive developmental period during which core cognitive and communicative abilities are formed making it a critical window for embedding the foundations of digital competence. International reports emphasise that the early primary years are formative for consolidating core literacy, communication, and self-regulation routines; therefore, introducing structured, age-appropriate digital practices at this stage is important for establishing foundations for later digital competence and for preventing equity gaps from widening (UNESCO, 2023; Gottschalk and Weise, 2023).

Globally, educational systems are placing greater emphasis on the development of digital competencies beginning in primary education. According to the DigComp 2.1 framework (Carretero et al., 2017) and the OECD Digital Literacy Framework (OECD, 2021), core skills such as information handling, digital communication, and personal data protection are now considered essential elements of 21st-century functional literacy. In countries such as Finland, Estonia, South Korea, and Canada, digital literacy has already been embedded into the national curriculum at the primary level, with a particular focus on cultivating metaskills such as critical thinking, collaboration, and the creative application of technology.

In this study, *digital skills* refer to task-level procedural abilities demonstrated in performance-based tasks (e.g., locating information, collaborating in a shared document, creating a simple digital artefact, applying basic safety routines). *Digital competence* is treated as the integrated, goal-directed use of these skills under classroom conditions and is operationalised through the DigComp-aligned diagnostic tool (Tables 1–5). The term *digital confidence* is reserved for pupils' self-perceived capability and is measured separately via self-assessment (Table 6).

However, as underscored in reports by the OECD and UNESCO, a persistent issue of digital inequality continues to affect primary-aged learners. In this paper, we use *digital inequality* as an umbrella term for structural disparities that shape children's opportunities to learn with technology, whereas the *digital divide* refers to the observable gap in access, use, and outcomes. In primary education, this gap is reflected in unequal access to devices and reliable internet, differences in parents' digital experience, and limited teacher capacity to integrate ICT effectively in early instruction (OECD, 2021; UNICEF, 2020). Children from rural areas, large families, or socially vulnerable backgrounds are especially at risk. Consequently, localized interventions aimed at developing digital skills among primary pupils are increasingly urgent, both to reduce access- and skills-related gaps and to support sustainable digital development within the school system.

TABLE 1 Structure and content of the digital skills diagnostic tool.

Component	Content description	Number of items
1. Information literacy	Searching, analyzing, and evaluating online information	5
2. Communication and interaction	Digital communication, online etiquette, file sharing	5
3. Content creation	Producing presentations, documents, and multimedia	5
4. Digital safety	Privacy, data protection, antivirus behavior	5

Despite the existence of both national and international programs aimed at integrating digital technologies into primary education, several contradictions remain unresolved. On one hand, curricula are gradually beginning to incorporate elements of digital literacy; on the other hand, classroom content often reduces such literacy to a formal introduction to tools, lacking any activity-based or learner-centered approach. At the same time, project-based learning (PBL) which emphasizes collaborative problem-solving in real-life contexts is widely regarded in educational research as one of the most effective strategies for fostering both functional and digital competence.

However, a review of current literature reveals that most studies continue to focus either on the use of ICT as an auxiliary resource for teachers or on evaluating the digital competencies of pre-service teachers. There are significantly fewer studies in which teacher education students are directly involved in conducting project-based work with primary school pupils. Yet this type of engagement is valuable not only for primary education but also for the teacher education system itself, as it highlights the potential of integrating project work into the university-level preparation of future educators. By participating in such modules, students enhance their metacompetencies, develop digital pedagogical maturity, and form a clearer sense of professional identity. Thus, the question of how student-led projects might directly contribute to developing digital skills in young learners remains insufficiently explored.

This study aims to address that gap. The goal of this empirical quasi-experimental research is to assess the effectiveness of project-based activities implemented by teacher education students in fostering digital skills among primary school pupils within the context of mainstream schooling.

Research objectives

1. To define and theoretically ground digital competence for primary learners and to examine how project-based learning (PBL) can support its development.
2. To develop DigComp 2.1-informed diagnostic instruments and to establish baseline profiles of pupils' digital competence prior to the intervention.
3. To develop and implement a structured system of project modules targeting the development of digital skills in the experimental group.
4. To conduct post-intervention assessments and compare quantitative outcomes between the control and experimental groups.
5. To analyze observational data collected through observation sheets tracking the progression of pupils' digital skills.
6. To substantiate the pedagogical effectiveness of the proposed model and offer recommendations for its replication in school practice.

TABLE 2 Results of pre-test by digital competence components (DigComp 2.1).

Digital competence components	Experimental group (M, SD)	Control group (M, SD)	t-value	*p*-value
Information literacy	2.38 (0.49)	2.35 (0.52)	0.29	0.772
Communication	2.51 (0.55)	2.56 (0.50)	−0.41	0.683
Content creation	2.44 (0.54)	2.48 (0.57)	−0.33	0.742
Safety	2.56 (0.51)	2.59 (0.53)	−0.27	0.788
Overall index	2.47 (0.52)	2.49 (0.55)	0.18	0.857

Independent-samples t-test, two-tailed; df = 122.

TABLE 3 Dynamics of pupils' digital competence levels in the experimental group.

DigComp component	Level	Before (%)	After (%)	Δ (%)
Information Literacy	Low	44	18	−26
	Medium	45	56	+11
	High	11	26	+15
Communication	Low	40	17	−23
	Medium	48	60	+12
	High	12	23	+11
Content Creation	Low	51	22	−29
	Medium	39	52	+13
	High	10	26	+16
Safety	Low	46	19	−27
	Medium	44	58	+14
	High	10	23	+13

Proficiency levels were derived from component scores on the 1–5 diagnostic scale: low (1.00–2.99), medium (3.00–4.49), high (4.50–5.00). Percentages represent the share of participants in each band.

Scientific contribution

This study contributes a replicable model of DigComp-aligned, student-facilitated PBL modules for Grades 2–4 and provides effect-size evidence from a quasi-experimental evaluation. The originality lies in operationalising university–school collaboration as a structured scaffolding mechanism for pupils' digital competence development (rather than positioning pre-service students as researchers).

Research questions

RQ1: How is digital competence defined and operationalized for Grades 2–4 pupils in this study, and which DigComp 2.1 domains are explicitly targeted by the intervention?

RQ2: What are the baseline levels of pupils' digital competence (overall and by domain), and are the experimental and control groups comparable at pre-test (T0)?

RQ3: How was the student-facilitated PBL intervention designed and implemented (module structure, scaffolding, digital tools, and dosage) in the primary classroom?

RQ4: What between-group differences are observed after the intervention at post-test (T1) and in gain scores (Δ) for overall digital competence and each domain?

RQ5: What patterns of progress in pupils' digital behaviors and strategies are documented in observation sheets, and how do these observational indicators converge with the quantitative results?

RQ6: What implementation constraints (e.g., *access to devices, connectivity stability, and classroom time*) *were salient during delivery, and what recommendations follow for replication in comparable school settings?*

Literature review

Digital competence in primary education: definition and operationalisation

Although "digital *competence*" is widely used in education policy and research, it becomes analytically useful only when defined in ways that can be observed and assessed in age-appropriate tasks. The DigComp framework offers a structured model of digital competence through clearly defined domains and competence descriptors (Carretero et al., 2017; Vuorikari et al., 2022). Importantly, applying DigComp logic to Grades 2–4 does not imply expecting advanced technical proficiency. Instead, it supports a developmental interpretation of competence as purposeful, guided tool use in learning contexts.

In this study, digital skills are treated as task-level, procedural abilities (e.g., using basic functions of a platform or app), whereas digital competence refers to the integrated and meaningful use of those skills to accomplish learning goals under classroom conditions (Carretero et al., 2017; Vuorikari et al., 2022). For primary-aged learners, this distinction is essential: competence is demonstrated when pupils can (a) locate and select relevant information for a task, (b) communicate and collaborate within rule-governed digital routines, (c) create simple multimodal artefacts (posters, presentations, short digital stories), and (d) apply foundational safety practices (privacy awareness, respectful online behavior, and basic password routines). At the national level, Kazakhstan's Digital Literacy Program for primary schooling reflects a policy intent to align local competencies with international frameworks (Ministry of Education and Science of the Republic of Kazakhstan [MES RK], 2021), while research continues to highlight implementation challenges related to teacher readiness and institutional capacity (Alférez-Pastor et al., 2023).

TABLE 4 Results of the final testing of digital competencies (M, SD).

Component	Experimental (M, SD)	Control (M, SD)	t	*p*	d
Information literacy	3.75 (0.45)	3.00 (0.52)	6.31	< 0.001	1.02
Communication	3.95 (0.42)	3.10 (0.50)	7.02	< 0.001	1.13
Content creation	4.20 (0.40)	3.15 (0.55)	8.45	< 0.001	1.34
Safety	3.50 (0.48)	3.05 (0.49)	3.22	< 0.001	0.52
Overall index	3.85 (0.44)	3.08 (0.51)	7.11	< 0.001	1.10

TABLE 5 Growth in digital competencies by component (Δ M, SD).

Component	Δ Experimental (M, SD)	Δ Control (M, SD)	t	*p*	d
Information literacy	1.37 (0.38)	0.65 (0.41)	5.71	<0.001	0.96
Communication	1.44 (0.42)	0.54 (0.45)	6.84	<0.001	1.05
Content creation	1.76 (0.40)	0.67 (0.49)	8.14	<0.001	1.28
Safety	0.94 (0.46)	0.46 (0.43)	3.12	<0.001	0.50
Overall index	1.38 (0.41)	0.58 (0.45)	7.45	<0.001	1.08

TABLE 6 Changes in self-assessment of digital skills (M ± SD, Pre/Post and Δ).

Indicator	Exp. Pre	Exp. Post	Δ Exp.	Ctrl. Pre	Ctrl. Post	Δ Ctrl.	t(122)	p	d
Overall perceived digital confidence (self-assessment)	2.63	4.05	1.42	2.67	3.21	0.54	6.95	< 0.001	1.25

Independent-samples t-test on gain scores (Δ), two-tailed; df = 122; Cohen's d computed from t and group sizes (n = 62 per group).

Why project-based learning can foster digital competence in early grades

Project-based learning (PBL) is commonly grounded in experiential and sociocultural traditions that emphasise active learning through meaningful activity and social mediation (Dewey, 1938; Vygotsky, 1978). Kolb's (1984) experiential learning cycle further clarifies how learning can be strengthened when action is coupled with reflection. In contemporary formulations, PBL is distinguished by sustained inquiry, authenticity, collaboration, and production of a tangible outcome, rather than by isolated "projects" as classroom events (Kokotsaki et al., 2016; Dias and Brantley-Dias, 2017).

This logic is directly relevant to digital competence because many digital behaviors in school are functional: pupils search, select, coordinate, create, revise, and present using digital tools. PBL makes these behaviors purposeful and socially distributed, thereby increasing opportunities for repeated enactment of target competencies. Empirical research in primary contexts supports the potential of well-structured PBL to foster broad competence indicators associated with twenty-first century skills, especially when projects are sequenced and guided (Rehman et al., 2023). For digital competence interventions, this literature also implies that domain-specific gains are likely to mirror task emphasis: domains repeatedly enacted in projects (often content creation and collaboration) may grow more strongly than those requiring routinised reinforcement (often safety), unless safety is systematically threaded through modules (Kokotsaki et al., 2016; Rehman et al., 2023).

Scaffolding as a condition of effectiveness: resolving the autonomy–guidance tension

A central debate in the PBL literature concerns the balance between learner autonomy and instructional guidance. From a cognitive load perspective, minimally guided approaches may be inefficient for novices because they can overload working memory and reduce learning effectiveness (Kirschner et al., 2006). In contrast, research on scaffolded inquiry argues that PBL and inquiry do not require the absence of guidance; rather, they depend on structured scaffolds (modeling, prompts, feedback, and staged task decomposition) that are gradually withdrawn as learners gain competence (Hmelo-Silver et al., 2007). This tension is particularly salient in early grades, where pupils typically require clear routines and close support to sustain collaborative work and regulate attention In the Kazakhstani primary-school context, Zhumabayeva et al. (2025) similarly foreground neuro-didactic principles in the design of learning content for younger pupils, reinforcing the argument that early-grade learning benefits from structured supports aligned with children's attentional and self-regulation capacities.

Within this debate, student-facilitated PBL can be theoretically justified as a delivery model that increases the density and quality of scaffolding during project work (Dias and Brantley-Dias, 2017; Hmelo-Silver et al., 2007). However, the same literature implies a methodological requirement: studies must report implementation features (scaffolding routines, facilitator roles, and intervention dosage) clearly, because "PBL" as a label is not sufficient for replication or for interpreting outcome patterns (Kokotsaki et al., 2016).

Digital divide and digital inequality: equity constraints on implementation

Terminological precision is important for interpreting results and for formulating recommendations. In this paper, the digital divide refers to measurable disparities in access and immediate conditions of use (devices, connectivity, and opportunities to engage with digital tools in learning). Digital inequality is treated as a broader concept capturing the structural patterning of such disparities through socio-economic resources, parental support, and institutional capacity, including teacher training and school-level resourcing (Gottschalk and Weise, 2023). Equity-focused syntheses caution that technology can either narrow or widen educational gaps depending on how it is implemented, how teachers are supported, and whether pedagogical design reduces dependence on out-of-school resources (Gottschalk and Weise, 2023; UNESCO, 2023). For school-based PBL aimed at digital competence, this implies the need to specify minimum technological requirements per module, document baseline access conditions, and embed safety routines consistently—so that competence development is not contingent on home resources.

Synthesis and alignment with study objectives and research questions

Taken together, the reviewed literature supports a focused logic for the present study. First, DigComp-informed work provides a coherent structure for defining digital competence and translating it into age-appropriate indicators for Grades 2–4, which directly informs instrument design and baseline profiling (Carretero et al., 2017; Vuorikari et al., 2022). Second, PBL research explains why sustained, product-oriented inquiry can generate meaningful opportunities to enact digital behaviors across information literacy, collaboration, and content creation (Kokotsaki et al., 2016; Rehman et al., 2023). Third, the autonomy–guidance debate clarifies that scaffolding is a necessary condition of effectiveness in early grades, motivating transparent reporting of facilitation routines and intervention dosage for replication (Hmelo-Silver et al., 2007; Kirschner et al., 2006). Finally, digital equity research frames contextual constraints that may shape feasibility and pacing of implementation, thereby informing replication recommendations for diverse school settings (Gottschalk and Weise, 2023; UNESCO, 2023).

Methodology

Research design

This study adopted a quasi-experimental, non-equivalent control group pretest–posttest design. The approach was selected because the intervention had to be implemented in intact classroom conditions, making individual randomization impractical. Allocation to conditions was performed at the class level to minimize disruption to the school schedule; therefore, the study is classified as quasi-experimental even though groups were balanced by grade and baseline characteristics. Intervention effects were estimated by comparing (a) post-test outcomes and (b) gain scores (T1–T0) between the experimental and control groups. Statistical analyses relied on independent-samples t-tests (Welch's t where assumptions were violated) and effect sizes (Cohen's d), complemented by structured observations to triangulate behavioral indicators of competence. Importantly, teacher-education undergraduates acted only as trained classroom facilitators; study design, data collection, and data analysis were carried out by the research team.

Participants

The study involved 124 primary school students (Grades 2 to 4) from a single mainstream school. Classes were randomly assigned into two groups: the experimental group ($n = 62$), in which students engaged in project-based learning facilitated by pre-service teachers from a pedagogical university, and the control group ($n = 62$), which followed the standard curriculum without additional project assignments. To ensure comparability, a stratified random sampling method was applied. Within each grade level (2nd, 3rd, and 4th grades), students were randomly distributed across groups while controlling for gender and baseline digital competence levels. This stratification reduced the impact of age and academic differences and supported internal validity. The two groups were statistically equivalent in terms of gender, age (mean age = 9.1 years), and initial digital skill levels ($p > 0.05$), thereby allowing for the use of Student's t-test to evaluate post-intervention differences. To implement the project modules, 24 fourth-year undergraduate students from the teacher training university were recruited. All participants had completed foundational coursework in pedagogy and underwent additional training in both project-based learning (PBL) methods and the use of digital educational tools prior to the intervention.

Within the quasi-experimental framework, the type of instruction served as the independent variable (traditional versus project-based with student-teacher involvement), while the dependent variable was the level of digital competence demonstrated by pupils. This competence was assessed across four core components of the DigComp 2.1 framework: information and data literacy, communication and collaboration, digital content creation, and digital safety. Changes in digital competence were measured before and after the intervention using a mixed-methods approach that included both a self-assessment scale and validated observational checklists. This dual strategy enabled a comprehensive evaluation of both quantitative progress and observational indicators in pupils' digital skill development. The study was conducted in a mainstream public primary school in Kazakhstan (site de-identified) following the national curriculum, including regular age-appropriate digital literacy activities. Grades 2–4 were selected because pupils at this stage typically have sufficient reading/writing and self-regulation skills to complete structured project tasks and performance-based digital assessments. Pupils were not pre-screened by prior technology experience; baseline testing (Table 2) was used to capture initial variation in digital competence.

Experimental procedure

The intervention phase of the experiment spanned one academic semester (16 weeks). During this period, six project-based learning (PBL) modules were implemented in the experimental group. These modules were specifically designed to cultivate core components of digital competence, including the ability to search and critically evaluate information, use online resources safely, collaborate in digital environments, create original digital content, and solve practical problems using ICT tools.

TABLE 7 Project-based learning modules implemented in the experimental group.

No.	Module title	Focus of digital competence	Digital tools used	Dosage (lessons/min)
1	"Treasure Hunt on the Web"	Information Literacy	Google, Yandex, Kiddle, Google Keep	5 × 45 min (225 min)
2	"Digital Footprint"	Digital Safety	Google Safe Search, Presentations, Videos	4 × 45 min (180 min)
3	"Teamwork Online"	Communication and Collaboration	Google Docs, Google Classroom, Padlet	6 × 45 min (270 min)
4	"My Family's History in Digital Form"	Creating Digital Content	Canva, Google Slides, Padlet	7 × 45 min (315 min)
5	"Interactive Map of My Homeland"	Information Literacy + Content Creation	Google My Maps, Canva, Google Sites	4 × 45 min (180 min)
6	"The Problem and Its Solution"	Problem Solving Using ICT	Jamboard, Google Forms, Google Presentations	4 × 45 min (180 min)

One school lesson equaled 45 min. The intervention was implemented over a 16-week window with two lessons per week (32 lessons in total). The six modules comprised 30 lessons (1,350 min = 22.5 h), while the remaining lessons were allocated to baseline and post-intervention assessment activities. Module dosage varied by task complexity (4–7 lessons per module). The "problem solving using ICT" module was treated as an integrative application module and was evaluated through performance indicators within the four assessed DigComp-aligned domains.

Each module was grounded in the pedagogical principles of project-based learning and involved collaborative assignments such as creating multimedia narratives, designing presentations, and developing interactive educational materials using platforms like Padlet, Canva, and Google Classroom (see Table 7). The pre-service teachers acted as facilitators: they organized student groups, provided ongoing guidance, and demonstrated effective strategies for utilizing digital tools. Their role was not to instruct directly, but to scaffold the learning process and promote digital autonomy among the pupils.

In the control group, instruction followed the standard curriculum without the inclusion of any additional project-based components.

Research instruments

To assess the level of students' digital skills, the following instruments were employed:

A DigComp-aligned diagnostic test of pupils' digital competence, covering four core domains: information literacy, communication, digital content creation, and online safety. In this study, digital skills refer to task-level procedural abilities demonstrated in performance-based tasks (e.g., locating information, collaborating in a shared document, creating a simple digital artefact, applying basic safety routines). Digital competence is treated as the integrated, goal-directed use of these skills under classroom conditions and is operationalised through a DigComp-aligned diagnostic tool (Tables 1–5). Digital confidenceis reserved for pupils' perceived capability and is measured separately via self-assessment (Table 6).

Observation checklists designed to capture students' behavior and strategies while completing project tasks, allowing for structured monitoring of engagement and tool usage.

A self-assessment questionnaire, using a 5-point Likert scale, aimed at evaluating pupils' digital confidence and perceived proficiency in using digital technologies.

Internal consistency of the diagnostic test was confirmed through the calculation of Cronbach's alpha ($\alpha = 0.82$), indicating high internal consistency. Content validity was ensured through expert review by three specialists in pedagogy and digital education.

Data collection and analysis

At the outset of the study, baseline testing was conducted to assess the initial level of digital competence among primary school students. Upon completion of the project-based modules, both the control and experimental groups underwent post-intervention testing and repeated self-assessment. Quantitative data were processed using SPSS version 26.0. Missing observations were minimal and were handled using a complete-case approach; the effective sample size is reported for each analysis where applicable. To evaluate differences between the control and experimental groups, Student's t-test for independent samples was employed, and Cohen's d was calculated to determine the effect size. In addition to standardized testing, observation checklists based on the DigComp 2.1 framework were used to track students' behavioral and practical demonstrations of digital skills during the project tasks. Each checklist comprised four domains aligned with digital competence (3–4 indicators per domain) and was filled in by student observers during group work sessions.

To ensure the reliability and validity of observations, inter-rater agreement procedures were implemented. This included pilot testing the observation instrument and conducting a calibration session involving 5 university instructors and 10 student observers. Inter-rater reliability was confirmed via Kendall's coefficient of concordance ($W = 0.84$), indicating a high level of agreement. Before conducting comparative analysis, key statistical assumptions were verified. The Shapiro–Wilk test was used to assess the normality of distributions, and Levene's test was applied to check the homogeneity of variances. In cases where assumptions were slightly violated, Welch's t-test was used to allow robust interpretation under heteroscedastic conditions. The significance level was set at $\alpha = 0.05$ (two-tailed), and Cohen's d effect sizes with 95% confidence intervals were reported to assess the magnitude of differences. Qualitative responses from student reflections were analyzed using thematic analysis following the six-step procedure outlined by Braun and Clarke (2006). For transparency, an example of the coding logic was as follows: "For the first time, I felt like a real teacher" → code *professional self-identification* → theme *emerging*

teacher identity. This included familiarization with the data, initial open coding, clustering codes into potential themes, refining thematic structures, and interpreting results in the context of pedagogical application. To enhance analytical rigor, codes were cross validated by two independent researchers.

Ethical considerations

The study adhered to ethical standards for research involving young children. Informed consent was obtained from parents and participating educators. Confidentiality and anonymity of all data were strictly maintained. The experimental protocol was formally approved by the Ethics Committee of Abai Kazakh National Pedagogical University.

Results

Baseline assessment: general level of digital skills

To assess the digital competence of primary school students, a diagnostic test was developed based on the DigComp 2.1 framework (Carretero et al., 2017). The instrument included 20 tasks, evenly distributed across four core components of digital competence. Each component was operationalized through five items that targeted essential skills relevant to the primary education context. The structure and content of the instrument are presented in Table 1.

Hereafter, the DigComp-aligned diagnostic tool is used to operationalize pupils' digital competence, while "digital skills" refers to task-level performance within the tool. The tool was specifically tailored to the developmental and cognitive characteristics of primary school students, ensuring age-appropriate language and context. It was administered in both paper and digital formats to accommodate different levels of digital access across the participating classes. Each domain was assessed using a five-point scale, where 1 indicated a minimal level of proficiency and 5 represented a high level of digital competence. The internal reliability of the instrument was confirmed by Cronbach's alpha coefficient ($\alpha = 0.82$), indicating a high degree of internal consistency across the diagnostic items. The diagnostic domains were aligned with the DigComp 2.1 framework (Carretero et al., 2017) and operationalised in age-appropriate tasks for Grades 2–4. This alignment should be interpreted as a pragmatic mapping of observable classroom actions to DigComp domains rather than a full psychometric validation of DigComp descriptors for this age group. For descriptive profiling, the 1–5 component scores were converted into three predefined proficiency levels: low (1.00–2.99), medium (3.00–4.49), and high (4.50–5.00). The same cut-offs were applied to all DigComp-aligned domains and to both measurement points.

The results of the baseline assessment confirmed that the digital competence levels of students in both the experimental and control groups were comparable and generally characterized as moderately low. A Student's t-test revealed no statistically significant differences between the two groups at the pre-test stage ($p > 0.05$), supporting the conclusion that the initial conditions were equivalent across groups. A more detailed breakdown of performance by digital skill domain is provided in Table 2.

To illustrate the distribution of mean values across digital skill domains, Figure 1 presents a comparative diagram. As shown, the indicators for all four components - information literacy, communication, content creation, and digital safety range from 2.3 to 2.6 points and are nearly identical in both groups. This graphical representation confirms the data from Table 2 and clearly demonstrates the absence of statistically significant differences at the outset of the experiment.

The test results confirmed that the initial level of digital competence in both groups was equally low, with no statistically significant differences observed. This provided a reliable baseline for comparing the subsequent dynamics during the experiment and enabled the interpretation of any emerging differences as a consequence of implementing student-led project-based activities.

Dynamics of change within groups

In addition, intra-group dynamics in the development of digital competencies were analyzed across the four dimensions of the DigComp framework. Students were classified according to predefined proficiency levels (low, medium, high) for each component,

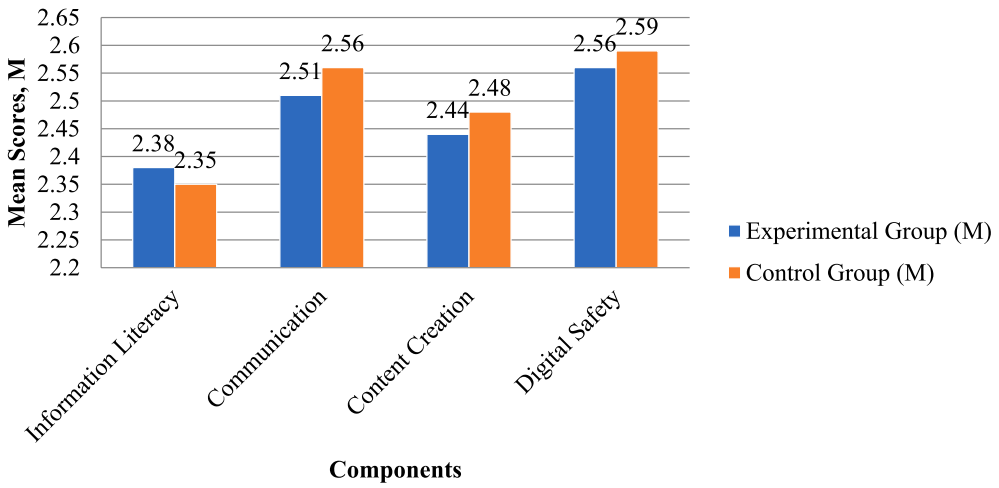

FIGURE 1
Average levels of students' digital competence in the control and experimental groups across four components (pre-test assessment, DigComp 2.1).

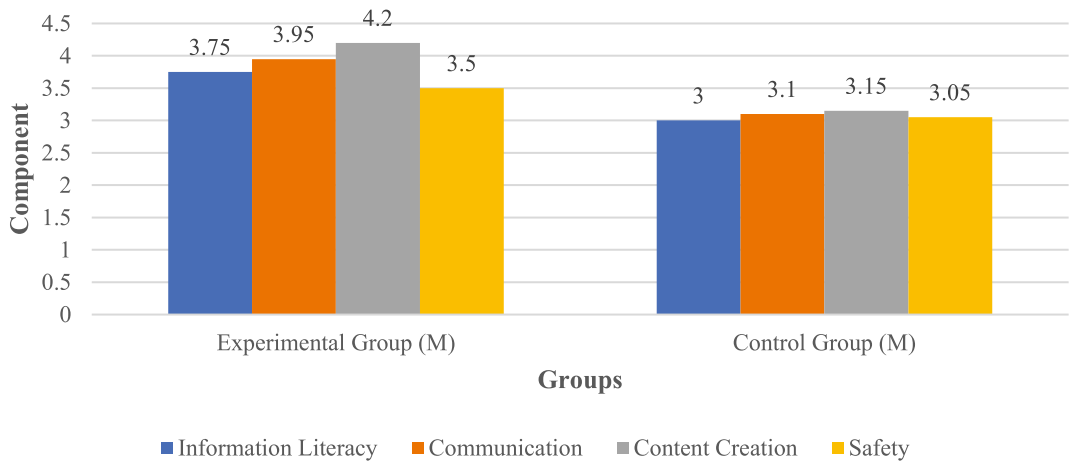

FIGURE 2
Mean scores of digital competence components (experimental and control groups, post-test).

both before and after the intervention. A summary of the results for the experimental group is presented in Table 3:

Overall, more than 80% of students in the experimental group demonstrated improvement in at least one competency area, while approximately 60% showed progress across two or more dimensions. The most notable shifts were observed in the domains of digital content creation and digital safety (Figure 2).

Final testing of digital competencies

The post-test conducted upon completion of the six project modules revealed statistically significant differences in digital competence levels between the experimental and control groups. The observed improvement in the experimental group was accompanied by a pronounced pedagogical effect (Cohen's d = 1.10), indicating the high effectiveness of integrating project-based activities into the learning process. The most substantial differences were recorded in the components directly related to the project tasks digital content creation and digital communication with large effect sizes according to Cohen's criteria. This suggests a strong influence of the project-based methodology on the development of creative and collaborative skills. The digital safety component showed moderate improvements. Detailed results are presented in Table 4.

Growth in digital competencies (Δ)

To enhance the validity of the digital competence assessment, gain scores (differences between post-test and pre-test values) were calculated for each component. A comparative analysis between the experimental and control groups revealed statistically significant differences across all areas of digital literacy. The most notable progress was observed in the components related to digital content creation and communication, which aligns closely with the focus of the project-based modules emphasizing creative and collaborative activity. These areas demonstrated a high level of pedagogical effect. Although less pronounced, the improvements in information literacy and digital safety were also statistically significant. The final digital competence index showed a marked advantage for the experimental group, confirming the effectiveness of the proposed instructional model. Detailed values are presented in Table 5.

The most significant gains were observed in content creation and communication, while the smallest improvement was recorded in digital safety (Figure 3).

Survey results of students

The results of the student survey, conducted using a 5-point Likert scale, revealed a significant increase in the level of competence in using digital technologies among participants in the experimental group. The changes were statistically significant and accompanied by a strong Cohen's effect size (d = 1.25), indicating not only a quantitative but also a qualitative improvement in students' self-assessment of their digital skills. In contrast, although the control group also demonstrated some positive dynamics, the improvement was notably less pronounced. These findings confirm that participation in project-based activities fosters not only the development of specific skills but also the formation of a positive attitude toward digital engagement. Detailed results are presented in Table 6.

Figure 4 presents a comparison of post-test digital literacy scores between the experimental and control groups across four domains. In all categories, students who participated in project-based learning demonstrated a clear advantage. The most significant differences were observed in the areas of Content Creation and Information Literacy. These results confirm the effectiveness of the implemented methodology in developing digital skills among primary school students.

The diagram illustrates that students in the experimental group achieved higher results across all five dimensions of digital literacy compared to those in the control group. The most pronounced advantages were observed in the areas of digital content creation (1.76 vs. 0.67) and information literacy (1.37 vs. 0.65), indicating substantial development of key competencies. The overall composite index of digital competence was also significantly higher in the experimental group (1.38 vs. 0.58). These findings confirm the effectiveness of project-based learning as a method for developing digital skills among primary school students.

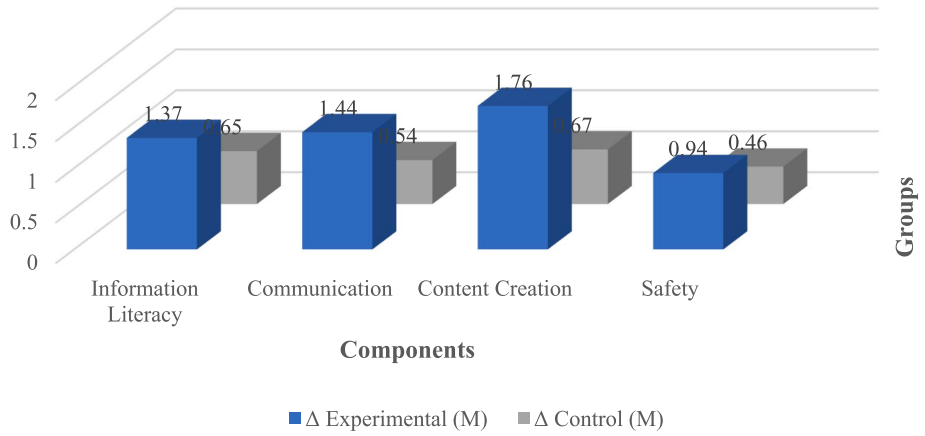

FIGURE 3
Growth in digital competencies by component (Δ).

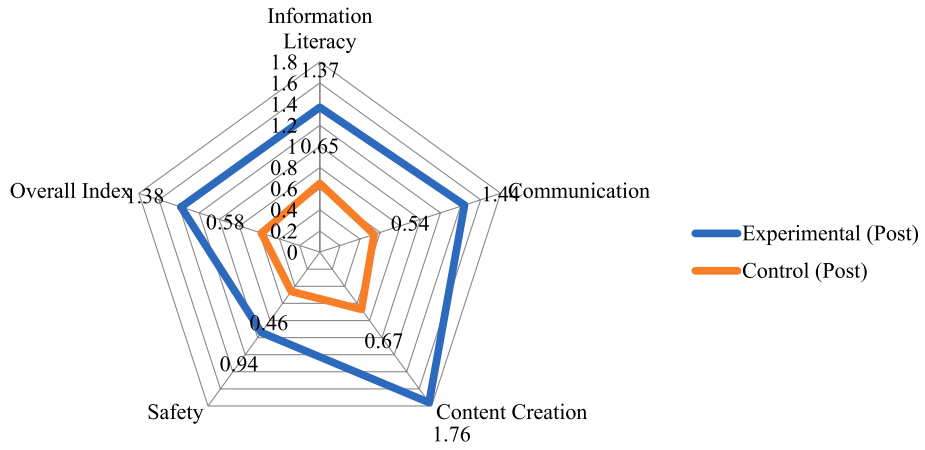

FIGURE 4
Comparative analysis of digital competencies among students (Likert scale, pre-post, EG vs. CG).

Qualitative analysis of observations

A thematic analysis of the observation sheets revealed the following conditions that contributed to the effective development of digital skills:

1. Structured scaffolding - continuous support from student-tutors during work with information and digital tools enhanced learners' engagement and success.
2. Explicit role distribution and cooperative organization - children within groups assumed specific roles (e.g., editor, designer, moderator), which stimulated digital communication and collaboration.
3. Presence of a final product - the requirement to present a digital presentation or multimedia material (e.g., via platforms like Padlet or Canva) increased motivation and responsibility among the learners.

These conditions offer a logical explanation for the significant improvements observed in the areas of content creation and communication. To assess the reliability of expert evaluations, Kendall's coefficient of concordance was calculated, yielding W = 0.84, indicating a high level of inter-expert agreement. This confirms the reliability of the instrument used and the validity of the qualitative findings. Normality of distributions was assessed using the Shapiro–Wilk test, and homogeneity of variances was verified via Levene's test. In cases of minor violations, Welch's t-test was applied, with significant differences still observed. All statistical analyses were conducted with a two-tailed $\alpha = 0.05$. Additionally, Cohen's d values with 95% confidence intervals were calculated to determine effect sizes.

Thematic analysis of student feedback

An analysis of students' reflections who participated in the experiment was conducted following the thematic approach proposed by Braun and Clarke (2006). Four key themes emerged:

Professional Self-Identification.

This theme was reflected in comments such as: "I felt like a real teacher," "I saw myself in the profession."

Growth in digital competence

Students frequently mentioned digital tools such as Canva, Padlet, and Jamboard, indicating the development of practical EdTech skills relevant to contemporary classroom contexts.

Emotional engagement

Statements such as "It was exciting but interesting," "I was scared but I managed," and "I felt joy from interacting with children" reflect the deep emotional involvement students experienced during their teaching practice.

Understanding of inclusion

Representative quotes included: "At first, I did not know how to approach children with special needs," "I learned to be patient," "It's important to see each child as a person." These themes emphasize that participation in the experimental setting served as a space for developing metacompetencies, fostering pedagogical reflection, and shaping the professional identity of future educators. Thus, the experiment fulfilled a dual function: on the one hand, it supported younger students in developing their digital skills; on the other, it contributed significantly to the professional growth of the student-teachers, equipping them with metacognitive skills, critical reflection abilities, and readiness to work in digital and inclusive school environments. Overall, the project-based activities implemented by students at the pedagogical university had a notable impact on the digital competence of primary school learners. This impact was especially prominent in the components related to content creation, presentation, and digital communication as confirmed by both quantitative results and qualitative data from self-assessments and observational reports.

Discussion

The findings indicate that involving student teachers as facilitators in project-based activities was associated with improvements in primary pupils' digital skills. Importantly, the model appears to have a dual focus: it supports pupils' confidence development while simultaneously contributing to the professional growth of student facilitators. These conclusions are grounded in the observed pre–post changes and the qualitative evidence collected during implementation. Addressing RQ1–RQ3, the study distinguished task-level digital skills from integrated digital competence and separated perceived digital confidence as a self-assessed construct measured independently (Table 6). Baseline testing confirmed pre-intervention equivalence between groups across DigComp-aligned domains (Table 2), supporting attribution of subsequent divergences to the intervention under the quasi-experimental design. The intervention itself was operationalised as six scaffolded PBL modules with specified dosage and tool ecology (Table 7), enabling replication and interpretation of domain-specific outcome patterns.

Impact of student-facilitated PBL on pupils' digital competence (RQ4)

Self-assessment gains were consistent with the observed performance improvements, but they capture perceived confidence rather than objective competence. In contrast, the control group displayed only limited change. Between-group post-test and gain-score contrasts were statistically significant for several outcomes (Tables 4–5), with several effects in the medium range (Table 5). Importantly, descriptive shifts in proficiency bands (low/medium/high) should be interpreted with reference to the predefined thresholds reported in Table 3.

Domain-specific effects across DigComp 2.1 components (RQ4)

The data analysis suggests that the most significant dynamics were observed in the following areas:

Digital content creation: through the production of multimedia artifacts (e.g., presentations, digital stories, flashcards), pupils developed a sense of authorship and accountability. This finding aligns with Alférez-Pastor et al. (2023), who highlighted increased critical thinking and autonomy among learners engaged in project-based work. Digital communication and collaboration - These skills were developed through structured group activities using platforms such as Padlet, Jamboard, and Google Classroom. As noted by Alférez-Pastor et al. (2023), digital collaboration fosters social digital competence, including empathy and negotiation skills in virtual environments.

Information literacy: this component improved as students were required to search for relevant content, evaluate sources, and synthesize information into project outputs. Such tasks stimulated metacognitive processes, resonating with the conclusions of Mota et al. (2025), who argue that PBL enhances both information filtering and digital reasoning skills. The digital safety component showed more modest progress, which may reflect the comparatively smaller share of safety-focused tasks within the six-module sequence and the need for repeated, routine practice to consolidate safety behaviors in early grades. Nevertheless, gains were observed in areas related to privacy awareness and digital footprint, which were addressed through embedded scenarios (e.g., password routines and discussion of online behavior).

Observed patterns and mechanisms of skills growth (RQ5)

Several distinctive features affirm the overall effectiveness of the proposed intervention:

Positive gains were recorded across all subgroups of learners, regardless of their initial level, suggesting the universal applicability of the model.

The short-term format (only six modules over three months) proved sufficient to develop basic digital competencies, owing to the intensity and targeted design of the learning tasks.

Observation protocols recorded more frequent pupil-initiated actions and sustained engagement during project tasks (e.g., independent tool selection, peer coordination, and iterative refinement of products). These patterns are consistent with higher engagement; however, motivation was not measured as a separate psychological construct and should therefore be interpreted cautiously.

The project-based learning environment functioned as both an instructional and a developmental space. Interpreting these classroom behaviors through Self-Determination Theory (SDT; Ryan and Deci, 2000), the project format plausibly supported pupils' sense of autonomy (choice within tasks), confidence (visible progress in products), and relatedness (collaborative routines). At the same time, SDT is used here as an interpretive lens rather than a directly tested mechanism, because need satisfaction was not measured explicitly.

TABLE 8 Pedagogical model of project-based activity: mapping student tasks to DigComp and facilitator competencies.

Elements of project-based learning	Digital skills developed in pupils (based on DigComp 2.1)	Meta-competencies formed in student teachers
Use of tools such as Canva, Padlet, Jamboard, etc.	Digital content creation (basic multimodal production); Communication & collaboration (sharing, co-editing, peer feedback)	Growth in digital pedagogical literacy; tool-mediated scaffolding
Design of project tasks ("create a poster," "design an infographic," "record a video interview")	Digital content creation (planning and producing artifacts aligned with task goals)	Instructional design for PBL; scaffolding design; teamwork planning
Work in mixed pairs / small groups (student–pupil collaboration)	Communication & collaboration (role distribution, coordination, netiquette in group work)	Facilitation skills; managing group dynamics; building pedagogical relationships
Guided information search activities (keywords, selection of relevant sources)	Information and data literacy (search, evaluation, synthesis for project outputs)	Mentorship in inquiry; formative feedback; pedagogical reflection
Final presentation of project outcomes (showcasing products, short explanations)	Communication & collaboration (presentation, discussion, peer commenting); Content creation (final polishing of artifacts)	Strengthening of professional identity; communication and feedback culture
Embedded safety routines and scenarios (password rules, privacy, digital footprint, online behavior)	Safety (privacy awareness, responsible behavior, basic security routines)	Responsible digital pedagogy; ethical sensitivity; safeguarding orientation

Implementation constraints and replication considerations (RQ6)

The intervention was implemented under real-school conditions, where access to devices, connectivity stability, and adult support for technology use may vary across pupils. These contextual factors can shape both the pace of skill acquisition and the feasibility of certain digital tasks. For replication, we recommend (a) documenting baseline access conditions at the class level (devices/connectivity), (b) specifying a minimum technological set required for each module, and (c) providing brief facilitator training focused on scaffolding strategies rather than direct instruction. Future implementations may also benefit from explicitly integrating short safety routines into every module to strengthen gains in the digital safety component.

Supplementary process evidence: facilitator reflections

As supplementary process evidence (not a primary study outcome), we analysed facilitator reflections from the pre-service teachers who supported implementation of the model. Their participation was embedded within the broader action research framework and a mixed-methods design, enabling the collection of valuable qualitative data through reflective reports, feedback narratives, and structured observations.

A thematic analysis of students' reflections (Braun and Clarke, 2006) revealed four dominant categories:

1. Professional self-identification: Students reported sentiments such as "For the first time, I felt like a real teacher."
2. Participants reported increased confidence and routine use of tools such as Canva, Padlet, Jamboard, and Google Classroom, and described how these tools were integrated into classroom facilitation.
3. Emotional engagement: Reflections indicated a shift from initial anxiety and uncertainty to confidence, joy, and emotional connection with pupils.
4. Understanding of inclusive education: Students developed a more ethically grounded and empathetic approach to interacting with children with special educational needs (SEN), reflecting statements like "I learned to be patient" and "It's important to see a personality in every child." This aligns with inclusive digital education approaches that combine problem/project-based learning with structured support for learners with special educational needs (D'Elia et al., 2025).

These thematic categories indicate the formation of key meta-competencies, including pedagogical reflection, digital maturity, and empathic capacity. Rather than functioning merely as teacher assistants, student participants acted as facilitators of the learning process, demonstrating the ability to respond flexibly to children's behavior, manage group dynamics, and establish a psychologically safe and digitally enriched learning environment. The visualization of the pedagogical model developed during the study is presented in Table 8. This model maps the relationships between the components of project-based learning, the specific digital competencies fostered in primary school pupils, and the meta-competencies formed in student teachers. The model illustrates the integrative and bidirectional nature of the intervention, confirming its dual impact both on learners and on future educators.

The implemented model demonstrated dual effectiveness: it simultaneously fostered digital competencies in primary school pupils and contributed to the development of pedagogical and digital meta-competencies in student teachers. This dual-impact design underscores the potential of project-based learning as a promising pedagogical component in both initial teacher training and broader strategies of educational digital transformation.

Conclusion

The study evaluated a student-facilitated project-based learning (PBL) model designed to develop DigComp 2.1-aligned digital

competence in Grades 2–4 pupils. The results provide convergent evidence that the intervention was effective under real-school conditions.

First, baseline testing confirmed that the experimental and control groups were comparable prior to the intervention (overall index: 2.47 ± 0.52 vs. 2.49 ± 0.55; $p = 0.857$), supporting the interpretation of post-intervention differences (RQ2). Second, after six PBL modules, the experimental group demonstrated significantly higher outcomes on the overall digital competence index (3.85 ± 0.44 vs. 3.08 ± 0.51; $p < 0.001$) with a large pedagogical effect ($d = 1.10$) and domain-specific gains across information literacy, communication/collaboration, content creation, and safety ($d = 0.52$–1.34), addressing RQ4. Third, pupils' self-assessed digital confidence increased more strongly in the experimental condition ($\Delta = 1.42$ vs. 0.54; $d = 1.25$), indicating that competence growth was accompanied by improved learner agency and readiness to engage with digital tasks. Finally, structured observations showed high inter-rater agreement (Kendall's W = 0.84) and documented more frequent pupil-initiated digital actions during project work, which triangulates the quantitative results (RQ5). Overall, the findings support the conclusion that student-facilitated, scaffolded PBL is a feasible and high-impact approach to strengthening primary pupils' digital competence. For replication, the strongest effects were observed in domains directly embedded in project production and collaboration; therefore, digital safety routines should be systematically integrated into each module through explicit micro-tasks and teacher mediation (RQ6).

Limitations of the study

Despite the positive results obtained, the present study has several limitations that should be considered when interpreting its findings.

First, the intervention was conducted over a relatively short period, which precludes conclusions about the long-term stability and retention of the digital skills developed among primary school students. Second, the sample was drawn from a single school, which limits the generalizability of the results to broader student populations and educational contexts. Third, although the observation protocols demonstrated a high level of inter-rater agreement (Kendall's W = 0.84), the potential for subjective interpretations of student behavior remains, particularly in assessing less overt indicators of digital competence. Fourth, the level of student-teacher engagement in the project activities may have varied depending on individual motivation, which could have influenced the consistency and efficacy of pedagogical support provided. Finally, while the DigComp 2.1 framework was adapted to align with the developmental characteristics of younger learners, its formal validation for this specific age group was not undertaken within the scope of this study. This limits the precision with which the resulting data can be interpreted and underscores the need for further validation of the assessment instrument in early education settings.

Although the instrument demonstrated high internal consistency, the DigComp-aligned operationalisation was not formally validated for primary-aged learners through factorial validation or measurement invariance testing. Future work should validate the structure of the instrument (e.g., cognitive interviewing with pupils, confirmatory factor analysis, and invariance checks across grades and gender) before wider use. These limitations should be taken into account when considering the scalability of the proposed model to other educational contexts and in the design of future research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Research Ethics Council of Abai Kazakh National Pedagogical University Republic of Kazakhstan, Almaty #2 Dated September 26, 2024. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin, for the publication of any potentially identifiable images or data included in this article.

Author contributions

BI: Writing – original draft, Formal analysis, Conceptualization, Validation, Writing – review & editing, Project administration, Methodology. AA: Data curation, Visualization, Methodology, Supervision, Writing – review & editing, Resources, Writing – original draft. KZ: Conceptualization, Project administration, Writing – original draft, Writing – review & editing, Investigation, Visualization. SA: Writing – original draft, Visualization, Resources, Formal analysis, Writing – review & editing, Investigation, Software. BA: Software, Writing – original draft, Funding acquisition, Resources, Writing – review & editing, Project administration. BS: Funding acquisition, Validation, Visualization, Writing – review & editing, Writing – original draft, Investigation.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that Generative AI was used in the creation of this manuscript. The authors used an AI-based tool for language

editing and formatting support under full author supervision; no new data, analyses, or references were generated by the tool. The authors take full responsibility for the content of the manuscript.

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