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IMPLEMENTING SCIENTIFIC PROJECT-BASED LEARNING IN COMPUTER PROGRAMMING COURSES: EVIDENCE ON QUALITY EDUCATION, LIFELONG LEARNING AND DECENT WORK SKILLS FROM KAZAKHSTAN

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ABSTRACT

Higher education is under pressure to translate programming instruction into demonstrable competence because technology employers recruit on evidence of applied problem-solving and teamwork rather than on course credits, and this gap between certification and capability constrains progress towards quality education, lifelong learning and decent work. This study investigates whether Scientific Project-Based Learning (SPBL), an instructional model that couples project work with systematic scientific inquiry, is associated with differentiated gains across four competence domains among undergraduate programming students: foundational programming skills, hands-on application of theory, problem-solving, and collaboration. The study employs cross-sectional survey data from 135 third-year and fourth-year students of the 6B061 Information and Communication Technologies in Education programme at M. Auezov South Kazakhstan University, Shymkent, Kazakhstan, all of whom completed a five-course programming sequence delivered through SPBL; perceptions were captured on a forced-choice four-point Likert instrument of eight statements and analysed using frequency distributions, item means, standard deviations, one-sample t-tests against the scale midpoint and Cohen's d. The results show that collaboration recorded the highest domain mean of 3.27 and problem solving 2.98, while hands-on application reached 2.73 and confidence in applying programming concepts recorded 2.39, the only item that did not differ significantly from the midpoint (t = -1.09, p = 0.278); effect sizes ranged from d = 1.13 to d = -0.09. The findings suggest that SPBL operates unevenly across competence domains, delivering large and consistent gains in collaborative and problem-solving capability while producing weak and heterogeneous gains in the transfer of theoretical knowledge into confident, independent coding practice.

INTRODUCTION

The information society has changed what a computing graduate is expected to do. Employers no longer treat a transcript as sufficient evidence of capability; they recruit on demonstrated ability to decompose an unfamiliar problem, to reason about trade-offs, to write code that others can maintain and to work inside a team that is itself learning. This shift places direct pressure on universities, because the instructional formats that reliably transmit syntax and language semantics are not the same formats that develop judgement under uncertainty. The resulting gap is not merely an employability concern. It is a barrier to the wider development agenda, since progress towards quality education and lifelong learning depends on

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graduates being able to convert formal instruction into productive capability, and progress towards decent work and economic growth depends on that capability being recognised by the labour market.

Computer programming is a particularly demanding case. It is a practical, skill-based field in which conceptual understanding and procedural fluency develop at different rates, and in which students frequently report understanding a concept during a lecture yet being unable to apply it in an unfamiliar context. Recent work on introductory programming has shown that learners follow markedly different trajectories through the same course, with score, engagement and problem-solving efficiency evolving as partially independent channels rather than as a single dimension of progress (Gao et al., 2025a, 2026). Anxiety and low self-efficacy compound the difficulty, and scaffolding decisions that appear minor to instructors can materially change how much of the course a novice actually attempts (Bolloju et al., 2026; Huang et al., 2025). Any pedagogical claim about programming instruction therefore needs to specify which competence it is claiming to develop.

Over several decades, a family of learner-centred approaches has been proposed to close this gap, including inquiry-based learning, problem-based learning and project-based learning. Meta-analytic syntheses report that these approaches generally outperform traditional instruction on achievement, motivation, creativity and computational thinking (Wijnia et al., 2024; Xu et al., 2023; L. Zhang & Ma, 2023; W. Zhang et al., 2024). Scientific Project-Based Learning (SPBL) is a distinct member of this family. It retains the authentic product orientation of project work. Still, it adds the disciplines of scientific inquiry, so that students formulate questions, justify design decisions with evidence, test alternatives systematically and report results in a form that another team could reproduce. The intended outcome is a graduate who has practised the profession's working methods, not only its vocabulary.

The scientific problem addressed in this paper arises from how this evidence base is typically reported. Studies overwhelmingly evaluate project-based instruction as a single treatment and report a single aggregate effect, implicitly assuming that the approach lifts all competence domains equally. That assumption is rarely tested directly, and where individual domains have been separated, the picture is uneven: collaborative and communicative gains appear robust, whereas the transfer of theory into independent practice appears sensitive to prior knowledge, group composition and engagement (Admiraal et al., 2026; Zhan et al., 2022). If the domains do, in fact, respond differently, then an aggregate effect size is not a useful guide for curriculum design because it conceals precisely the information an instructor needs to decide where additional scaffolding is required. The problem is sharper still in Central Asia, where empirical evidence from computing programmes remains scarce and where curriculum reform is proceeding on the basis of findings imported from other educational systems.

This research aims to determine whether SPBL is associated with uniform or differentiated gains across four competence domains of undergraduate programming students. The study pursues this aim through a cross-sectional survey of 135 third-year and fourth-year students who completed a five-course programming sequence delivered entirely through SPBL. Perceptions were recorded on a forced-choice four-point Likert instrument comprising eight statements grouped into four domains, and the responses were analysed using frequency distributions, item means and standard deviations, one-sample t-tests against the scale midpoint, and standardised effect sizes.

The remainder of the article is organised as follows. The literature review traces the origins and theoretical foundations of project-based learning, examines how the approach has been evaluated in computing and engineering education, identifies the unresolved question of domain-specific response, and states the study's purpose and hypotheses. The materials and methods section describes the instructional context, the five-course programming sequence, the participants, the instrument and the analytical procedure. The results section reports the response distributions, descriptive statistics and hypothesis tests. The discussion interprets these results in light of previous findings and considers why the domains diverge. The conclusions summarise the contribution, set out the theoretical and practical implications, acknowledge the limitations, and propose directions for further research.

LITERATURE REVIEW

Research on project-based learning is unusual in that its historical origins are themselves contested, and the competing accounts matter because they attach different purposes to the method. One account traces the project idea to sixteenth-century Italy, where socio-economic conditions prompted the Academy of Arts in Rome to train architects and artists through commissioned works rather than by imitating models. This arrangement made the finished artefact the instrument of assessment. A second and more widely accepted account locates the origin in the pragmatic pedagogy that emerged in the United States in the late nineteenth and early twentieth centuries, a reform movement that sought to connect schooling to lived experience and to organise instruction around learners' natural activities and interests. John Dewey was the pivotal figure in that movement, arguing that education consists in the continuous reconstruction of a learner's expanding personal experience rather than in the transmission of settled content.

Kilpatrick (1918) converted Dewey's problem-oriented philosophy into an explicit instructional method. He defined the project as a purposeful act carried out in a social setting, organised around a theme that the learner has reason to care about, and he argued that the educative value lies in the purposefulness rather than in the artefact. This framing established the features that continue to define the approach: hands-on experience, problem-solving, teamwork, social competence, and accountability for a shared outcome. Its lasting importance is that it made the learner's intention, rather than the instructor's syllabus, the organising principle of the activity.

Contemporary treatments position project-based learning as a constructivist instructional approach that is context-specific, actively engages learners, and pursues its objectives through social interaction and the exchange of understanding (Cocco, 2006; Dutta & Chanda, 2024). Almulla (2023) elaborates on the same constructivist logic in higher education and reports that it operates indirectly on academic performance through critical thinking, creativity, and problem-solving activities, rather than directly through the format itself. This distinction is important for the present study, because it implies that the format alone does not guarantee learning gains; the cognitive work the format provokes is what produces them.

The method is closely related to, but distinguishable from, neighbouring approaches. Helle et al. (2006) characterise project work as collaborative learning in which every participant must contribute to a common outcome, and note that it draws on experiential learning while requiring deliberate reflection rather than passive exposure. Al-Balushi and Al-Aamri (2014) treat it as a specific form of inquiry-based learning in which the learning context is defined by authentic questions drawn from real situations. Kokotsaki et al. (2016) locate the sharpest distinction in the deliverable: project-based learning requires students to produce a concrete artefact that demonstrates understanding, whereas problem-based learning requires them to propose a solution to a stated problem. Thomas (2000) provides the most widely used operational definition, identifying centrality, a driving question, constructive investigation, autonomy, and realism as the five defining characteristics, and emphasising cooperation, self-reflection, and the public presentation of outcomes.

Quantitative synthesis over the last two years has strengthened the general case for the approach while also revealing its variability. Wijnia et al. (2024) conducted a meta-analysis of problem-based, project-based, and case-based learning. They found consistent positive effects on student motivation, with the magnitude depending on the extent to which the design supported learner autonomy. X. Zhang et al. (2024) synthesised thirty-one experimental and quasi-experimental studies on computational thinking. They reported gains in innovation, collaboration, critical analysis, algorithmic cognition, and problem resolution, with the profile of gains shifting by educational stage: collaborative gains dominated at primary level.

In contrast, critical-analytical gains dominated at higher levels. Rosa and Salvador (2025) reviewed implementation frameworks and concluded that outcomes depend heavily on structural design choices such as task granularity, assessment alignment and the scheduling of feedback. Taken together, these syntheses indicate that the approach is not a uniform treatment and that reporting a single effect size may obscure more than it reveals.

Evidence from computing and engineering education points in the same direction with greater specificity. Husin et al. (2025) combined project and problem formats for engineering undergraduates and observed significant improvements in problem-solving skills, as well as positive perceptions of critical thinking and collaboration. Pawar and Desai (2026) evaluated a structured framework in an undergraduate engineering context. They found that gains were most visible where assessment explicitly rewarded the reasoning process rather than the finished artefact. Afzal and Tumpa (2025) used action research in project management education. They reported that group work improved learning outcomes only when task interdependence was designed deliberately, since loosely coupled tasks allowed students to work in parallel without genuine exchange. O'Connor et al. (2026) surveyed first-year engineering students in an online module and found generally positive satisfaction with teamwork and collaborative attitudes, while noting that satisfaction with collaboration and perceived learning gain were only loosely related.

Programming-specific research adds a further caution about transfer. Gao et al. (2025b) traced learning trajectories in an introductory programming course. They showed that score, engagement and code quality follow distinct sequences for computer science and mathematics cohorts studying the same material. Gao et al. (2025a) subsequently modelled competency evolution as a multi-channel process, and Gao et al. (2026) demonstrated that these patterns differ systematically by disciplinary background. Loksa et al. (2022) argue that metacognition and self-regulation are the mechanisms that determine whether a learner converts activity into competence. Ramirez-Echeverry et al. (2025) report that the strategies students actually deploy vary with course level and task structure. These findings imply that an instructional format which increases activity does not automatically increase transfer, since transfer depends on regulatory processes that the format may or may not support.

Self-efficacy operates as a parallel constraint. Huang et al. (2025) found that visual programming instruction improved flow experience, programming self-efficacy and sustained willingness to learn, indicating that affective outcomes respond to instructional design. Bolloju et al. (2026) showed that starter-template scaffolding reduced coding anxiety in introductory courses, and Uslu and Unal (2026) identified perceived learning level in programming as a function of both prior preparation and instructional support. Liu et al. (2024) and X. Zhang et al. (2024) examined self-efficacy and collaboration attitudes in programming under different pairing arrangements and found that group composition materially changed both. Zhan et al. (2022) reached a similar conclusion regarding group size, reporting effects on achievement, motivation, cognitive load, and the quality of collaborative problem-solving. Collectively, this body of work suggests that collaborative outcomes are relatively robust to design variation, whereas individual confidence in applying concepts is not.

The wider skills literature explains why this asymmetry matters beyond the classroom. Rizakhojayeva et al. (2025) synthesised meta-analytic and empirical findings on soft-skills development in STEM contexts. They concluded that structured collaborative activity is among the most dependable routes to communication and teamwork competence. Alabri and Shannaq (2025) modelled employability outcomes and found that soft skills mediated the relationship between technology adoption and employability, indicating that collaborative competence carries direct labour-market value. Faisal-E-Alam (2024) reported comparable results for structured training programmes and trainee learning. Xu et al. (2023) established through a meta-analysis that collaborative problem solving promotes critical thinking, thereby providing a mechanism linking the collaborative and analytical domains examined in the present study.

Technology-mediated learning research supplies a final consideration. Jiang et al. (2025) found that the benefit of digital tools for students' practical performance was mediated by cognitive load: tools that reduced extraneous load improved performance, whereas those that increased it did not. Chowdhury et al. (2024) documented that learner attitudes towards technology-mediated delivery vary substantially within a single population, and Pande et al. (2024) found comparable heterogeneity in university students' awareness and use of artificial intelligence tools. Ravi et al. (2025) and Kamberovic et al. (2025) examined how generative tools are being incorporated into project-based and programming instruction, noting that these tools can substitute for the productive struggle on which transfer depends. Kazemitabaar et al. (2023) reached a similar conclusion regarding code generators used by novices, and Yang et al. (2024) showed that reflective assessment is one mechanism capable of restoring the analytical work that automation removes.

Scientific Project-Based Learning occupies a particular position within this literature. It preserves the authentic product orientation of project work while adding the procedural discipline of scientific inquiry, so that students formulate testable questions, justify design decisions with evidence, compare alternatives systematically and document results reproducibly. Shin et al. (2021) show that project-based designs can be explicitly configured to support computational thinking through modelling, which is close to the mechanism that SPBL is intended to exploit. The distinguishing claim of SPBL is therefore not that students build something, but that they build it using the reasoning procedures of the discipline.

Three conclusions follow from this review. First, the general effectiveness of project-based instruction is well established. Still, effect sizes are heterogeneous and sensitive to design choices, which limits the usefulness of aggregate estimates for curriculum planning. Second, the evidence that does separate competence domains suggests an asymmetry: collaborative and problem-solving outcomes appear robust, whereas the transfer of theoretical knowledge into confident, independent practice appears fragile and dependent on prior knowledge, engagement, and regulatory support. Third, this asymmetry has not been tested directly within a single cohort exposed to a sustained programming sequence, and almost no such evidence exists for Central Asian higher education, which leaves curriculum reform in the region reliant on findings generated under different institutional conditions.

The purpose of this study is therefore to determine whether Scientific Project-Based Learning, implemented across a five-course undergraduate programming sequence, is associated with uniform or differentiated gains across four competence domains, and to quantify the magnitude of any difference between them. Based on the reviewed literature, the following hypotheses are formulated:

H_1: Students exposed to SPBL report improvement in foundational programming skills that is significantly above the scale midpoint.
H_2: Students exposed to SPBL report improvement in the hands-on application of theoretical knowledge that is significantly above the scale midpoint.
H_3: Students exposed to SPBL report improvement in problem-solving and analytical skills that is significantly above the scale midpoint.
H_4: Students exposed to SPBL report improvement in collaboration and peer-to-peer learning that is significantly above the scale midpoint.
H_5: The magnitude of reported improvement differs across the four competence domains rather than being uniform.

MATERIALS AND METHODS

The study uses a cross-sectional, non-experimental survey design. Because SPBL is the standard mode of delivery for the entire programming sequence in the programme under study, no untreated control group exists within the cohort, and a between-groups comparison was therefore not available. The design instead evaluates perceived gains against a fixed criterion, namely the midpoint of the response scale. It compares the magnitude of those gains across competence domains within the same respondents. This within-subject comparison is the principal analytical device of the study, since it is unaffected by the absence of a control group: any tendency of respondents to over-report or under-report gains applies equally across all four domains and therefore cannot, by itself, produce a difference between them.

Students specialising in 6B061 Information and Communication Technologies in Education at M. Auezov South Kazakhstan University complete a sequence of five programming courses, each delivered through SPBL and each assessed principally through a group project carried out on an authentic topic. The sequence is designed so that project complexity, autonomy and the required depth of investigation increase from course to course, while the assessed deliverable shifts progressively from a working artefact towards a justified design supported by evidence. Table 1 summarises the sequence.

Table 1. Structure of the five-course programming sequence delivered through SPBL

Course	Principal content	Language or environment	Assessed project
First	Pseudocode, algorithms, flowcharts, functions, methods, control structures	C++	Group project on a real-world topic, presented to the class
Second	Object-oriented paradigm: classes, objects, inheritance, polymorphism, abstraction, GUI construction	Java	Group database-driven application
Third	Event-driven development, string manipulation, event, file and error handling, database connectivity, report generation	Visual Basic	Group event-driven application with reporting
Fourth	Transition to web development, CSS styling, multimedia authoring, educational software design	ASP.NET	Educational software for primary or secondary schooling
Fifth (elective)	Advanced mobile development, advanced software development with remote databases and recovery, or open-source web development	Android Studio, Visual Studio (VB.NET or ASP.NET), or PHP	Advanced group application in the chosen stream

Note. Each course is assessed principally through a group project. Project complexity, required autonomy and depth of investigation increase across the sequence.

The target population comprised third-year and fourth-year students enrolled in the 6B061 programme who had completed at least four courses of the programming sequence. All eligible students were invited, and 135 completed the instrument, of whom 72 were in the third year and 63 in the fourth. Because the entire eligible population was approached rather than a probability sample, the responses describe this cohort directly, and generalisation beyond it rests on argument about similarity of context rather than on sampling theory. Participation was voluntary and anonymous; no incentive was offered, no identifying information was collected, and students were informed that participation would not affect assessment in any course.

Perceptions were measured using a purpose-built instrument of eight statements organised into four domains of two statements each: improvement in programming skills, application of hands-on knowledge, development of problem-solving skills, and collaboration and teamwork. Each statement was answered on a forced-choice, four-point Likert scale, scored as 1 for strongly disagree, 2 for disagree, 3 for agree, and 4 for strongly agree. The even number of response options follows the argument of Allen and Seaman (2007) that a midpoint invites two incompatible interpretations, genuine neutrality and unwillingness to answer, which cannot be distinguished afterwards. Removing it forces a directional judgement and balances the response categories. The design cost of this choice is that respondents who hold no view must nonetheless choose a side, which is likely to inflate the counts in the two central categories. Table 2 lists the statements.

Table 2. Survey domains and statements

Item	Domain	Statement
Q1	Programming skills	SPBL helped me improve my basic programming skills.
Q2	Programming skills	I feel more assured in my ability to apply programming concepts due to SPBL.
Q3	Hands-on knowledge	SPBL has helped me connect theory with practice in programming.
Q4	Hands-on knowledge	I feel better prepared to solve real-world coding problems thanks to SPBL.
Q5	Problem solving	SPBL improved my skills to solve complex programming problems.
Q6	Problem solving	I can break down and analyse programming tasks better after engaging in SPBL.
Q7	Collaboration	SPBL promotes collaboration among students, enhancing teamwork and communication skills.
Q8	Collaboration	Group-based SPBL enhances peer-to-peer learning in computer programming courses.

Note. All statements were answered on a four-point scale: 1 = strongly disagree, 2 = disagree, 3 = agree, 4 = strongly agree.

Responses were tabulated as frequencies and percentages for each item. Item means and standard deviations were then computed using the 1-to-4 metric. Because the instrument has no midpoint, the theoretical scale centre is 2.5, representing the point at which agreement and disagreement are exactly balanced; a mean above 2.5 therefore indicates net agreement, and a mean below it indicates net disagreement. Each item was tested against this value using a one-sample t-test with 134 degrees of freedom, and the standardised mean difference was expressed as Cohen's d. Domain scores were computed as the mean of the two constituent item means. Hypotheses H_1 to H_4 were assessed by the direction and significance of the domain items, and H_5 by comparing effect sizes across domains.

Two measurement decisions require explicit statement. First, all analysis in this paper uses a strict 1-to-4 scoring metric. Second, item means are computed directly from the reported frequency distributions rather than from any prior summary, so that every statistic reported below is reproducible from Table 3 alone. The instrument uses two items per domain, which is sufficient for descriptive comparison but too few to support a stable internal consistency coefficient; no reliability estimate is therefore reported, and this is treated as a limitation rather than an omission.

RESULTS

Table 3 reports the full response distribution for each of the eight statements, together with the mean, standard deviation, one-sample t statistic against the scale midpoint of 2.5, the associated p value and Cohen's d. All 135 respondents answered every item, so there is no missing data.

Table 3. Response distribution and descriptive statistics for the eight survey items (n = 135)

Item	SD n (%)	D n (%)	A n (%)	SA n (%)	Mean	SD	t (df = 134)	p	d
Q1	12 (9)	11 (8)	55 (41)	57 (42)	3.16	0.92	8.41	< 0.001	0.72
Q2	42 (31)	28 (21)	35 (26)	30 (22)	2.39	1.15	-1.09	0.278	-0.09
Q3	26 (19)	26 (19)	40 (30)	43 (32)	2.74	1.11	2.53	0.013	0.22
Q4	24 (18)	27 (20)	46 (34)	38 (28)	2.73	1.06	2.47	0.015	0.21
Q5	7 (5)	15 (11)	58 (43)	55 (41)	3.19	0.83	9.66	< 0.001	0.83
Q6	24 (18)	23 (17)	49 (36)	39 (29)	2.76	1.06	2.88	0.005	0.25
Q7	3 (2)	14 (10)	64 (48)	54 (40)	3.25	0.73	11.96	< 0.001	1.03
Q8	1 (1)	16 (12)	61 (45)	57 (42)	3.29	0.70	13.09	< 0.001	1.13

Note. SD = strongly disagree, D = disagree, A = agree, SA = strongly agree. Percentages are rounded and may not sum to exactly 100. Means and standard deviations are computed on a 1 to 4 metric. The t statistic tests the item mean against the scale midpoint of 2.5. Cohen's d is the standardised difference from that midpoint.

The first domain, improvement in programming skills, produced the widest internal divergence of any domain in the study. Q1, which asked whether SPBL improved basic programming skills, attracted agreement or strong agreement from 83 per cent of respondents and yielded a mean of 3.16, significantly above the midpoint with a medium effect ($t = 8.41$, $p < 0.001$, $d = 0.72$). Q2, which asked whether students felt more assured in applying programming concepts, produced a mean of 2.39 and was the only item in the study that did not differ significantly from the midpoint ($t = -1.09$, $p = 0.278$, $d = -0.09$). Its distribution is close to bimodal, with 31 per cent selecting "strongly disagree" and 22 per cent "strongly agree," and its standard deviation of 1.15 is the largest observed. The domain mean of 2.78 therefore averages two genuinely different results and should not be read as a single finding. H_1 is supported for the acquisition of foundational skills but not for confidence in applying them.

The second domain, application of hands-on knowledge, produced consistent but modest results. Q3 recorded a mean of 2.74 ($t = 2.53$, $p = 0.013$, $d = 0.22$) and Q4 a mean of 2.73 ($t = 2.47$, $p = 0.015$, $d = 0.21$), giving a domain mean of 2.73. Both items exceed the midpoint significantly, so H_2 is supported; however, the effect sizes are small, and the standard deviations, at 1.11 and 1.06, are among the highest recorded. Approximately 38 per cent of respondents disagreed or strongly disagreed with each statement. The substantive interpretation is that SPBL moves the average student only slightly beyond neutrality on the transfer of theory into practice, and that the cohort is genuinely divided rather than uniformly moderate.

The third domain, problem-solving skills, again separated into two distinct results. Q5, concerning complex problem solving, produced a mean of 3.19 with the second-lowest dispersion in the study ($t = 9.66$, $p < 0.001$, $d = 0.83$), and 84 per cent of respondents agreed or strongly agreed. Q6, concerning the decomposition and analysis of programming tasks, produced a mean of 2.76 ($t = 2.88$, $p = 0.005$, $d = 0.25$) with a standard deviation of 1.06 and 35 per cent disagreement. The domain mean is 2.98. H3 is supported for both items, but the larger effect for solving problems collaboratively and the smaller effect for decomposing them analytically are the more informative results, pointing to a skill that develops within the group rather than within the individual.

The fourth domain, collaboration and teamwork, produced the strongest and most consistent results in the study. Q7 recorded a mean of 3.25 ($t = 11.96$, $p < 0.001$, $d = 1.03$) with 88 per cent agreement and only 2 per cent strong disagreement, and Q8 recorded a mean of 3.29 ($t = 13.09$, $p < 0.001$, $d = 1.13$) with 87 per cent agreement and a single respondent strongly disagreeing. The domain mean of 3.27 is the highest observed, and the two items have the lowest standard deviations in the study at 0.73 and 0.70, indicating that this is also the domain on which the cohort is most nearly unanimous. H4 is supported with large effects.

Table 4. Domain-level results and hypothesis outcomes

Domain	Items	Domain mean	Effect size range (d)	Agreement range (%)	Hypothesis outcome
Programming skills	Q1, Q2	2.78	-0.09 to 0.72	48 to 83	H1 partially supported
Hands-on knowledge	Q3, Q4	2.73	0.21 to 0.22	62 to 62	H2 supported (small effects)
Problem solving	Q5, Q6	2.98	0.25 to 0.83	65 to 84	H3 supported (uneven effects)
Collaboration and teamwork	Q7, Q8	3.27	1.03 to 1.13	87 to 88	H4 supported (large effects)

Note. Domain mean is the arithmetic mean of the constituent item means. Agreement combines the agree and strongly agree categories.

Table 4 summarises the domain-level pattern and provides the direct test of H_5. The four domain means are ordered as collaboration (3.27), problem solving (2.98), programming skills (2.78), and hands-on knowledge (2.73), and the effect sizes range from $d = -0.09$ to $d = 1.13$. The distance between the strongest and weakest items is more than a full standard deviation. Dispersion follows the same ordering in reverse: the two collaboration items have standard deviations of 0.73 and 0.70, whereas the four items concerning individual application and analysis range from 1.06 to 1.15. The gains are therefore not uniform in magnitude, nor in how widely they are shared across the cohort. H_5 is supported.

One further pattern in the data deserves separate mention because it is not visible in the domain means. The four items with the largest standard deviations, namely Q2, Q3, Q4 and Q6, are precisely the four items that ask about something the individual student must be able to do alone: apply a concept, connect theory to practice, transfer to an unfamiliar problem, and decompose a task analytically. The four items with the smallest dispersion, Q1, Q5, Q7 and Q8, ask about outcomes that are produced or observed within the group. Consistency of response, in other words, tracks whether the outcome is collective or individual, which is a structural feature of the results rather than an incidental one.

DISCUSSIONS

The central finding of this study is that Scientific Project-Based Learning did not lift all four competence domains together. Collaboration recorded effects above one standard deviation with near-unanimous agreement, whereas confidence in applying programming concepts did not differ significantly from the scale midpoint at all. This is a difference of kind rather than of degree, and it is invisible in any aggregate summary of the intervention. The result therefore supports the concern raised in the literature review that reporting project-based instruction as a single treatment with a single effect conceals the information that curriculum designers most need.

The collaborative findings align closely with previous work and can be regarded as well established. Rizakhojayeva et al. (2025) concluded from meta-analytic and empirical evidence that structured collaborative activity is among the most dependable routes to communication and teamwork competence, and the present effect sizes of $d = 1.03$ and $d = 1.13$ sit comfortably within that expectation. O'Connor et al. (2026) similarly reported high satisfaction with teamwork among engineering students working in project-based formats. W. Zhang et al. (2024) found collaboration to be one of the five computational-thinking dimensions most consistently improved by project-based designs. The mechanism is not mysterious: SPBL makes collaboration structurally unavoidable, because the assessed deliverable cannot be produced without division of labour, negotiation of interfaces and reconciliation of conflicting design decisions. Students practise these behaviours whether or not they are motivated to do so, and the instructional format therefore guarantees exposure.

The weak transfer findings are more theoretically interesting, and they require an explanation rather than a restatement. Almulla (2023) argued that constructivist formats affect academic performance indirectly, through the critical thinking and problem-solving activity they provoke, rather than directly through the format itself. If that account is correct, then a format guarantees only the opportunity for the relevant cognitive work, not its occurrence. Loksa et al. (2022) identify metacognition and self-regulation as the processes that determine whether such an opportunity is taken, and Ramirez-Echeverry et al. (2025) show that the regulatory strategies students actually deploy vary considerably by course level and task structure. On this reading, the divided response to Q2 reflects genuine variation in whether individual students engaged in the reasoning that transfer requires, rather than measurement noise.

Group dynamics offer a complementary and more specific explanation, one that the dispersion pattern in the present data directly supports. Afzal and Tumpa (2025) found that group work improves learning only when task interdependence is deliberately designed, because loosely coupled tasks allow students to work in parallel without genuine exchange. Zhan et al. (2022) reported that group size affects achievement, motivation, cognitive load, and the quality of collaborative problem-solving. W. Zhang et al. (2024) and Liu et al. (2024) demonstrated that pairing arrangements materially change programming self-efficacy. In a group project, division of labour is efficient, and the efficient allocation is to assign each subtask to whoever is already most competent at it. That arrangement reliably produces a good artefact and collaboration, which this study measured as d> 1.0. It does not require every member to practise every skill, as individual transfer would. The observation that the four items with the highest dispersion are precisely those asking about individually held capability, while the four with the lowest dispersion ask about collectively produced or observed outcomes, is consistent with this account.

Findings on the problem-solving domain reinforce the same interpretation from a different angle. Solving complex problems, which in a project setting is a group activity supported by discussion, produced a large effect at d = 0.83. Decomposing and analysing tasks, an individual cognitive operation, had a small effect (d = 0.25) despite belonging to the same nominal domain. Xu et al. (2023) established through a meta-analysis that collaborative problem solving promotes critical thinking, and the present data are consistent with this relationship while suggesting that the transmission is partial: the collaborative activity develops readily, whereas the internalised analytical capacity develops less readily.

Two boundary conditions on this interpretation should be stated. First, the outcome measure is student perception rather than demonstrated performance, and the relationship between the two is imperfect. Perceived and actual learning gains diverge in predictable directions, and collaborative satisfaction, in particular, is only loosely related to measured learning outcomes (O’Connor et al., 2026). It is therefore possible that the collaboration result partly reflects the visibility and social pleasantness of group work rather than competence gain, and that the transfer result partly reflects the well-documented difficulty students have in judging their own competence in a domain where the ceiling is not visible. Second, the study offers no untreated comparison, so the results indicate where students perceive SPBL to have helped them most and least, rather than the magnitude of improvement relative to conventional instruction.

Within these limits, the practical implication is specific. The parts of the curriculum that were expected to be difficult, namely collaboration, communication, and joint problem-solving, were delivered reliably by the instructional format itself. The part that was implicitly assumed to follow automatically, namely each student's confident command of the concepts, did not follow for a substantial minority of the cohort. Where mechanisms have been shown to strengthen individual regulation, including reflective assessment (Yang et al., 2024), scaffolding calibrated to reduce anxiety (Bolloju et al., 2026), and structural design choices that align assessment with reasoning rather than output (Pawar & Desai, 2026; Rosa & Salvador, 2025), these represent the natural targets for redesign. The emergence of generative tools makes this more, rather than less, pressing, since such tools can remove precisely the productive struggle on which individual transfer depends (Kamberovic et al., 2025; Kazemitabaar et al., 2023).

CONCLUSIONS

The purpose of this study was to determine whether Scientific Project-Based Learning, implemented across a five-course undergraduate programming sequence, is associated with uniform or differentiated gains across four competence domains, and to quantify the difference between them. Survey evidence from 135 third-year and fourth-year students established that the gains are markedly differentiated. Collaboration and peer-to-peer learning recorded domain means of 3.27 on a four-point scale with effect sizes of 1.03 and 1.13 and agreement of 87 to 88 per cent. Problem solving recorded a domain mean of 2.98, split internally between collaborative problem solving (effect size 0.83) and individual task decomposition (effect size 0.25). Hands-on application of theory recorded 2.73 with small effects of approximately 0.21. Confidence in applying programming concepts recorded a score of 2.39 and did not differ significantly from the scale midpoint, the only such result in the study.

The conclusion is that the instructional format guarantees the collective outcome but only enables the individual one. Collaboration is structurally unavoidable in group project work, because the deliverable cannot be completed without it, and it therefore develops dependably across the whole cohort. Individual command of concepts is not structurally guaranteed because an efficient division of labour allows each member to contribute what they already do best, and therefore it develops unevenly. The dispersion of responses corroborates this reading: items concerning collectively produced outcomes attracted the most uniform responses, while items concerning individually held capability attracted the most divided ones.

The study contributes to knowledge in three ways. It provides domain-separated rather than aggregate evidence on project-based instruction within a single cohort exposed to a sustained programming sequence, showing that a single effect size for such an intervention is misleading. It provides quantified evidence from Central Asian higher education, a context in which empirical research on computing education remains scarce and curriculum reform has relied on findings generated elsewhere. It also identifies a structural explanation, grounded in the division of labour within project groups, for an asymmetry observed piecemeal in prior work but not framed as a systematic property of the format.

For practice, the implication is that SPBL should be retained for the outcomes it delivers dependably and supplemented for those it does not. Programme designers should not assume that individual conceptual command follows from group project success. They should introduce mechanisms that require every member to demonstrate their individual capability, such as rotating technical roles across projects, individual defence of design decisions, reflective assessment tasks, and periodic individual assessment on unfamiliar problems. For institutions pursuing quality education and graduate employability, the practical value of the collaborative gains should not be understated, since teamwork and communication are precisely the competences that employers report as scarce.

Several limitations qualify these conclusions. The outcome is self-reported perception rather than demonstrated performance, and the two are known to diverge. The absence of an untreated comparison group means that the results identify relative strengths and weaknesses within SPBL rather than its advantage over conventional instruction. The instrument uses only two items per domain, which is too few to support a stable estimate of internal consistency, and the forced-choice, four-point format compels a directional answer from respondents who may hold none. The sample is drawn from a single programme at a single university, and the cross-sectional design cannot establish causal direction. Data on gender, prior programming experience and academic standing were not collected, which prevents examination of the subgroup differences that the dispersion in the individual-capability items strongly suggests are present.

Future research should address these limitations directly. The most valuable next step would be to pair perceptual measures with objective assessments of individual programming performance on unfamiliar problems to determine whether the perceived transfer deficit reflects an actual one. Quasi-experimental comparison with conventionally taught cohorts would quantify the incremental contribution of SPBL. Longitudinal tracking across the full five-course sequence would show whether the transfer gap narrows with exposure or persists. Collecting group composition data would permit direct testing of the division-of-labour explanation proposed here, and replication across institutions and national contexts would establish how far these findings generalise. Finally, given the rapid adoption of generative tools in programming education, further work should examine how their availability alters the balance between collective delivery and individual competence in project-based settings.

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