Project-Based Learning in Gifted Computer Science Education: Collaborative Problem-Solving and Learning Performance Across Semesters

Noramalina Mohd Hatta

Pusat PERMATA@Pintar Negara UKM, Universiti Kebangsaan Malaysia, Malaysia

DOI: https://doi.org/10.47772/IJRISS.2026.100701200

Received: 09 August 2026; Accepted: 14 August 2026; Published: 24 August 2026

ABSTRACT

Project-Based Learning (PBL) provides opportunities for learners to engage in authentic problem-solving, collaboration, and application of disciplinary knowledge. However, empirical evidence concerning its implementation among gifted and talented learners in secondary Computer Science education remains limited. This study examined the implementation of PBL among gifted and talented students in a secondary Computer Science programme, with particular attention to collaborative problem-solving and learning performance across semesters. A mixed-methods approach was employed involving 33 gifted and talented students aged 16 to 17 at Kolej PERMATA@Pintar Negara, Universiti Kebangsaan Malaysia. Quantitative data were obtained from students' continuous assessment and peer-evaluation scores, while qualitative evidence was collected through student reflection surveys and classroom observations. The findings indicated differences in students' learning performance across semesters, while peer-evaluation results suggested generally positive perceptions of teamwork and individual contribution. Student reflections further indicated positive experiences of engagement and collaboration, while classroom observations documented behaviours including role negotiation, task sharing, and peer feedback during project activities. The findings suggest that PBL provides a promising context for integrating collaborative problem-solving, authentic computing tasks, and active learning among gifted and talented learners. Nevertheless, the findings also highlight the importance of strengthening structured reflection, differentiation, and systematic approaches to examining group dynamics and individual participation. The study contributes contextual evidence on the application of PBL within gifted secondary Computer Science education and provides directions for future research and pedagogical development.

Keywords: Project-Based Learning; gifted and talented students; Computer Science education; collaborative problem-solving; learning performance; gifted education

INTRODUCTION

Gifted and talented learners require educational experiences that provide appropriate levels of intellectual challenge, flexibility, and opportunities for advanced learning. Contemporary gifted-education research emphasizes the importance of pedagogical and educational approaches that support the development of gifted learners' potential and respond to their educational needs. A systematic review by Baccassino and Pinnelli (2023) identified numerous instructional and educational programming models for gifted students and highlighted the importance of appropriate educational planning to support their development. In particular, differentiation has been identified as an important approach for addressing differences in readiness, interests, learning pathways, and levels of challenge among high-ability learners. A systematic scoping review of 38 studies identified 15 differentiation approaches used with high-ability students across primary and secondary settings, including challenge and higher-order thinking, catering for interests, open-ended problem-based inquiry, student choice, and multiple learning pathways. The review also highlighted the need for further research across a broader range of educational contexts (Nicholas et al., 2024)

These considerations are particularly relevant to Computer Science education, where students are expected to apply computational concepts to complex problems, develop solutions iteratively, and integrate knowledge across programming, data, algorithms, and emerging technologies. Project-Based Learning (PBL) provides a

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

potentially suitable pedagogical approach because it places learners in active problem-solving situations that require investigation, application, collaboration, and creation. Recent evidence provides support for the relationship between PBL and computational thinking. In a meta-analysis of 31 experimental and quasi-experimental studies, Zhang et al. (2024) found that PBL was associated with improvements across several dimensions of computational thinking, including innovation, collaboration, critical analysis, algorithmic thinking, and problem-solving. These findings suggest that PBL can provide a meaningful context for developing computational competencies through extended and applied learning activities.

The potential value of PBL may be particularly relevant for gifted learners because project-based environments can provide opportunities for open-ended inquiry, greater learner autonomy, and differentiated levels of task complexity. However, the application of PBL within gifted education cannot be assumed to produce the same outcomes across all learners or contexts. Differentiation remains important because high-ability students have diverse needs, potentials, interests, and levels of readiness, requiring teachers to select and adapt approaches according to individual learners and learning objectives (Nicholas et al., 2024). Consequently, PBL implementation in gifted Computer Science education requires attention not only to the use of projects but also to how projects are structured, supported, assessed, and adapted to learners' needs.

Although PBL has received increasing attention in computing and computational-thinking education, its specific application to gifted and talented learners in structured secondary Computer Science programmes remains comparatively underexplored. Existing research has established benefits of PBL for computational thinking and related learning outcomes, but fewer studies have examined how gifted learners experience PBL when projects require sustained collaboration, problem-solving, reflection, and application of computing knowledge over an extended period. This represents an important research gap because gifted learners may require differentiated levels of challenge and learning support that are not necessarily addressed by general PBL implementations.

The context of Kolej PERMATA@Pintar Negara, Universiti Kebangsaan Malaysia (UKM), provides an appropriate setting for examining this issue. The institution provides education for gifted and talented learners, and Project-Based Learning is integrated into the Computer Science curriculum for students aged 16 to 17. Within this context, students undertake extended computing projects involving areas such as Data Science and Internet of Things (IoT), requiring them to apply computational knowledge to practical problems while working collaboratively with peers. Such an environment provides an opportunity to examine not only students' academic performance but also their experiences of collaboration, problem-solving, engagement, and learning across an extended PBL experience.

Accordingly, this study examines the application of PBL as a pedagogical approach for gifted and talented students in Computer Science education. The study focuses particularly on collaborative problem-solving and students' learning performance across semesters, while also considering students' perceptions and reflections on their PBL experiences. By combining quantitative indicators of academic performance and peer evaluation with qualitative evidence from student reflections and classroom observations, the study seeks to provide a more comprehensive understanding of how PBL operates within a gifted computing education context.

The primary objective of this study is to examine how PBL supports collaborative problem-solving and learning among gifted and talented students in Computer Science education. Specifically, the study addresses the following research question:

1. How does Project-Based Learning influence collaborative problem-solving and learning outcomes among gifted and talented students in Computer Science education?

The study contributes to literature by examining PBL at the intersection of gifted education and computing education, an area that remains comparatively underexplored. The findings are intended to provide practical and research-based insights into the design of PBL experiences that incorporate collaboration, differentiated challenges, reflection, and authentic computing tasks for high-ability learners.

LITERATURE REVIEW

Project-Based Learning in Computer Science Education

Project-Based Learning (PBL) is a student-centred instructional approach that engages learners in practical and inquiry-oriented learning activities. Within computing education, PBL has attracted attention because of its potential to connect computational thinking with applied problem-solving and collaborative learning. Saad and Zainudin (2022), in a systematic review of PBL and computational thinking, found that the existing literature was concentrated primarily in computing and STEM contexts and reported generally positive findings associated with PBL-CT integration. However, they also identified limited availability of explicit frameworks, models, tools, and techniques to guide the integration of PBL and computational thinking. More recent evidence strengthens this relationship: Zhang et al. (2024) synthesized 31 experimental and quasi-experimental studies and found significant effects of PBL across innovation, collaboration, critical analysis, algorithmic thinking, and problem-solving. Evidence from Computer Science education also indicates benefits associated with independent learning, teamwork, real-life project experiences, critical thinking, and collaboration, although implementation challenges such as time constraints and team complexities remain (Dema & Choden, 2024).

PBL and Gifted and Talented Learners

Gifted education provides a distinctive context for PBL because high-ability learners represent a diverse population with differing needs, interests, readiness, and potential. Baccassino and Pinnelli (2023), in a systematic review of gifted-education research published between 2011 and 2021, identified numerous instructional and educational programming models for gifted students and emphasized the importance of personalized educational planning to develop learners' potential.

More specifically, Nicholas et al. (2024) conducted a systematic scoping review of 38 studies examining differentiation for high-ability learners. The review identified 15 teaching approaches across primary and secondary settings, including challenge and higher-order thinking, catering for interests, open-ended problem-based inquiry, student choice, and multiple learning pathways. The review also highlighted the diversity of high-ability learners and the importance of considering contextual factors when implementing differentiation approaches.

Of particular relevance to PBL, open-ended, problem-based inquiry was identified in 23 of the reviewed studies. This approach allowed students to pursue different paths of inquiry and develop different solutions, including through engagement with challenging real-world problems. These findings provide a conceptual basis for considering how PBL characteristics may support differentiation for high-ability learners, particularly when projects allow variation in complexity, inquiry pathways, and learner choice. However, this conceptual alignment does not establish that PBL is automatically effective for gifted learners. Rather, its potential value depends on how project complexity, learner autonomy, support, assessment, and collaborative structures are designed and implemented within particular educational contexts.

Collaboration and Collaborative Problem-Solving in Computing

Collaboration is an important dimension of project-based learning because extended projects require learners to communicate ideas, coordinate activities, and work jointly toward shared solutions. In computing education, this collaborative dimension is particularly relevant to programming and computational problem-solving, where learners may need to develop, test, evaluate, and refine solutions collectively. Li et al. (2024) examined a metacognitive-regulation-based collaborative programming system in a junior-high-school programming course and investigated its effects on learning achievement, computational-thinking tendencies, and group metacognition. Their findings provide evidence for the value of structured collaborative programming approaches in supporting both individual and group-level learning processes.

Collaboration is also relevant to gifted education. In a case study of mathematically gifted students, Lee (2022) found that collaborative problem-solving enabled students to share different solution approaches, understand alternative perspectives, and use these perspectives to evaluate their own and their peers' reasoning. These findings suggest that collaborative problem-solving can provide gifted learners with opportunities to encounter and evaluate multiple approaches to complex problems. At the same time, collaborative problem-solving should be considered as a process rather than only as an outcome. Ouyang et al. (2023) demonstrated that collaborative problem-solving involves dynamic and multimodal interaction patterns and that different patterns of communication and behaviour can be associated with different levels of group performance.

This perspective has implications for the assessment of collaboration in PBL. Peer-evaluation scores can provide useful information about students' perceptions of contribution and teamwork, but observations of interaction and group processes can provide additional insight into how collaborative problem-solving develops. Examining communication, role distribution, individual contribution, negotiation of solutions, and participation patterns may therefore provide a more comprehensive understanding of collaboration during complex computing projects.

Metacognition and Reflection in PBL

Metacognition is an important consideration in learning because it involves learners' awareness and regulation of their own cognitive processes. This may be particularly relevant to gifted learners. Tibken et al. (2022), in a longitudinal study of gifted and non-gifted adolescents, found that procedural metacognitive competence contributed to the development of school achievement among gifted students beyond the contribution of intelligence.

The relationship between metacognition and collaborative computing is also supported by recent research. Li et al. (2024) developed a metacognitive-regulation-based collaborative programming system for junior-high-school students and found that students who used the metacognitive-regulation approach demonstrated significantly higher learning achievement, computational-thinking tendencies, collective efficacy, and metacognitive planning and evaluation than students in the comparison condition.

Reflection provides one practical mechanism through which metacognitive processes can be incorporated into learning. Guo (2022), in a meta-analysis of 23 reflective-intervention studies involving 2,010 higher-education participants, found a positive, statistically significant medium-sized effect of reflective interventions on learning outcomes. The effects varied according to intervention duration, peer interaction, and reflective activities, suggesting that the design of reflection activities may influence their effectiveness. Evidence from PBL research also indicates that reflection and self-report measures can be used alongside observations, assessments, and project artefacts to examine students' learning processes and outcomes (Guo et al., 2020).

Taken together, these findings provide a rationale for incorporating reflection throughout PBL rather than treating it solely as an end-of-project reporting activity. In the present study, student reflection was incorporated as one of the qualitative data sources to capture students' experiences, learning strategies, and perceptions of the PBL process.

Authentic and Applied Computing Learning

An important characteristic of PBL in Computer Science education is its capacity to connect classroom learning with practical applications and contextual problems. In a Malaysian secondary-school Computer Science context, Abdull Jabbar and Abd Halim (2024) found that technology-integrated PBL was associated with improved Python programming performance and described PBL as a strategy for engaging students in problem-solving and real-world challenges. In the context of IoT education, Bunyamin (2023) demonstrated how an IoT-based PBL model could integrate theoretical and practical knowledge, collaborative learning, and contextual problem-solving while providing students with greater autonomy in decision-making. Similarly, Collaguazo et al. (2023) examined academic IoT projects and highlighted the need to integrate hardware and software components while addressing real-life problems during project development.

These findings suggest that computing projects can provide learning environments in which students apply technical knowledge to practical problems rather than treating programming and computational concepts as isolated skills. This authentic dimension is particularly relevant to the present study, in which students undertake projects involving Data Science and Internet of Things (IoT) and are required to integrate computing knowledge, make design decisions, solve practical problems, and work collaboratively toward project outcomes.

Research Gap

The literature reviewed provides evidence supporting PBL, computational thinking, differentiation, collaboration, and metacognition as relevant dimensions of computing and gifted education. However, several areas require further investigation. First, although PBL and computational thinking have received increasing research attention, the studies reviewed here largely examine general student populations rather than explicitly identified gifted and talented learners in secondary Computer Science programmes. The meta-analysis by Zhang et al. (2024) found positive effects of PBL on computational thinking and reported differences in effect sizes across educational levels, highlighting the importance of examining PBL within specific learner and educational contexts.

Second, research on gifted education has identified differentiation approaches such as challenge and higher-order thinking, catering for interests, open-ended problem-based inquiry, student choice, and multiple learning pathways (Nicholas et al., 2024). However, the reviewed literature provides limited evidence regarding how these differentiation principles operate within PBL environments specifically designed for gifted Computer Science learners. The findings of Nicholas et al. (2024) further highlight the importance of considering differentiation within diverse educational contexts.

Third, the literature reviewed provides limited evidence examining collaborative problem-solving and metacognitive processes together within gifted computing education. Li et al. (2024) demonstrated the potential of integrating metacognitive regulation with collaborative programming, but their study involved junior-high-school students rather than a specifically identified gifted population. Similarly, research involving gifted learners has demonstrated the value of collaborative problem-solving for sharing solution approaches and evaluating alternative perspectives (Lee, 2022), but this evidence is situated primarily in mathematics rather than Computer Science.

Finally, methodological research on PBL emphasizes the value of using multiple forms of evidence to examine different dimensions of learning, including assessments, observations, questionnaires, reflections, and project artefacts (Guo et al., 2020). This suggests the value of examining both learning outcomes and learning processes when evaluating PBL rather than relying on a single measure.

Taken together, the literature indicates a need for further empirical examination of PBL within gifted secondary Computer Science education, particularly regarding collaborative problem-solving, learning performance across semesters, and students' reflective experiences. The present study addresses this need by examining PBL within the context of gifted and talented learners undertaking extended Computer Science projects involving Data Science and Internet of Things (IoT) applications.

METHODS

This study employed a convergent parallel mixed-methods design to investigate the effectiveness of Project-Based Learning (PBL) for gifted and talented students in computer science education. This design enables the simultaneous collection of both quantitative and qualitative data, offering a well-rounded perspective on how PBL influences collaboration, and long-term learning. The mixed-methods approach is particularly suited to this study as it captures both measurable academic impacts and the experiential learning processes of high-ability students.

The participants were 33 gifted and talented students aged 16 to 17 enrolled in the Computer Science program at Kolej PERMATA@Pintar Negara, UKM. Selection was based on academic excellence and national-level gifted identification criteria. These students were involved in a series of PBL activities integrated into their Computer Science curriculum, with projects designed to promote real-world problem-solving, peer collaboration, and reflective learning.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

Quantitative data were collected through academic performance marks before and after PBL that measured student learning, confidence in problem-solving, and perceived learning outcomes to assess the impact on learning achievement. The data were collected as marks for their continuous assessment consisting of two semesters. These assessments are required to be completed by the students for a complete academic year.

Qualitative data were obtained from students' reflective learning survey, which documented their thoughts, experiences, and learning strategies throughout the PBL process. In addition, structured classroom observations were conducted using predefined rubric focusing on learner engagement, peer interaction, and demonstration of problem-solving skills during project activities. All instruments used such as surveys, observation rubrics, and journal guidelines, were adapted from validated sources and reviewed to ensure reliability and alignment with the study objectives.

Data analysis for the quantitative component included descriptive statistics and measured significant differences in outcomes before and after the PBL evaluation for the final project. For the qualitative data, thematic analysis was applied to identify patterns and insights related to collaboration, self-directed learning, and conceptual understanding. The integration of these data sources ensured triangulation and enhanced the credibility of the findings.

RESULTS

This section presents the results obtained through a PBL method approach, integrating both quantitative and qualitative data to evaluate the impact of PBL on gifted and talented students for 16 to 17 years of Level 1 students in a group project that is needed to be completed for a full academic year known as Final Year Project and consists of 2 to 3 group members by solving a Data Science and Internet of Things problems. This research uses data consisting of two semester results and each semester mark is collected as a continuous assessment with overall marks of 100. To get effectiveness in this study, the value that is taken into consideration is based on the standard deviation in Computer Science marks for each semester. If the standard deviation is low, it indicates that the the students' scores are clustered closely around the mean, reflecting highly consistent learning outcomes and greater equity in performance across the entire cohort.

Quantitative Findings

Collaborative Problem-Solving Skills

Collaborative learning was assessed through peer evaluation scores collected at the end of each project cycle. Table 1 shows the average score increased from Semester 1 with mean of 18.18 and standard deviation 3.82 to Semester 2 by average score obtained is 18.77 and standard deviation 2.62, indicating a slight improvement in perceived teamwork and contribution. Although the difference was not statistically significant the reduction in score variance suggests greater equity and consistency in group collaboration. These findings imply that students may have adapted to collaborative expectations over time, demonstrating more balanced participation and improved group management skills, which are essential in PBL environments. Notable gains were observed in criteria such as algorithmic thinking, logical sequencing, and creative solutions. These results support the hypothesis that PBL enhances computational thinking and applied problem-solving abilities. Students were observed actively negotiating roles, sharing tasks, and integrating feedback from peers effectively. Lecturers noted that high-ability learners thrived in group-based problem-solving, often proposing creative or non-standard solutions to open-ended challenges.

Table 1. Peer Evaluation Score for Computer Science (PBL)

Types of Assessment	Average Score	Standard Deviation	Total Students
Semester 1	18.18	3.82	33
Semester 2	18.77	2.62	

Long-Term Learning Outcomes

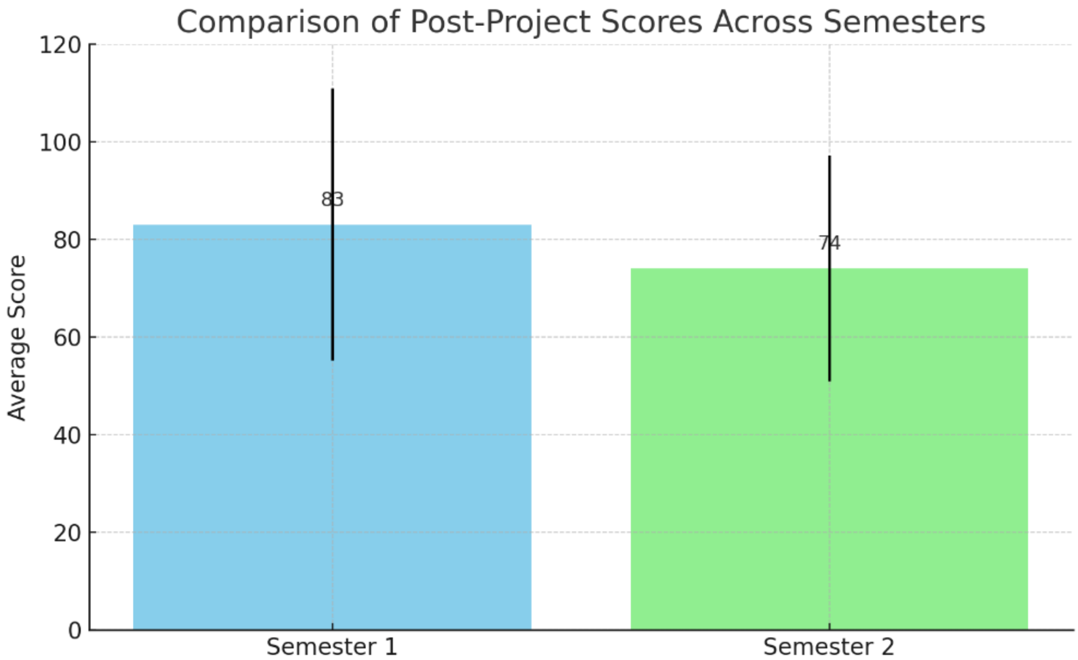
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VII July 2026

Based on Figure 1, in Semester 1, students achieved an average score of 83, with a standard deviation of 27.82, while in Semester 2, the average score was 74, with a standard deviation of 23.07. These results suggest that students maintained a strong grasp of computational concepts over time, demonstrating the ability to apply their knowledge meaningfully in final project tasks.

Although there is a noticeable decline in the average score from Semester 1 to Semester 2, both averages remain relatively high, indicating that the PBL approach fostered sustained learning. The standard deviations, while moderate, suggest a diverse range of outcomes within the student group, reflecting the varied learning trajectories typical among gifted learners. This variability may be influenced by differences in individual interest, group collaboration dynamics, or the complexity of the projects in each semester.

Despite the decrease in average score, the overall performance across both semesters' points to the effectiveness of PBL in promoting long-term learning retention. The drop in scores may highlight the need for additional scaffolding or adjustments in project difficulty to maintain consistent performance levels across semesters.

Figure 1 Comparison of Post Project Scores Across Semesters

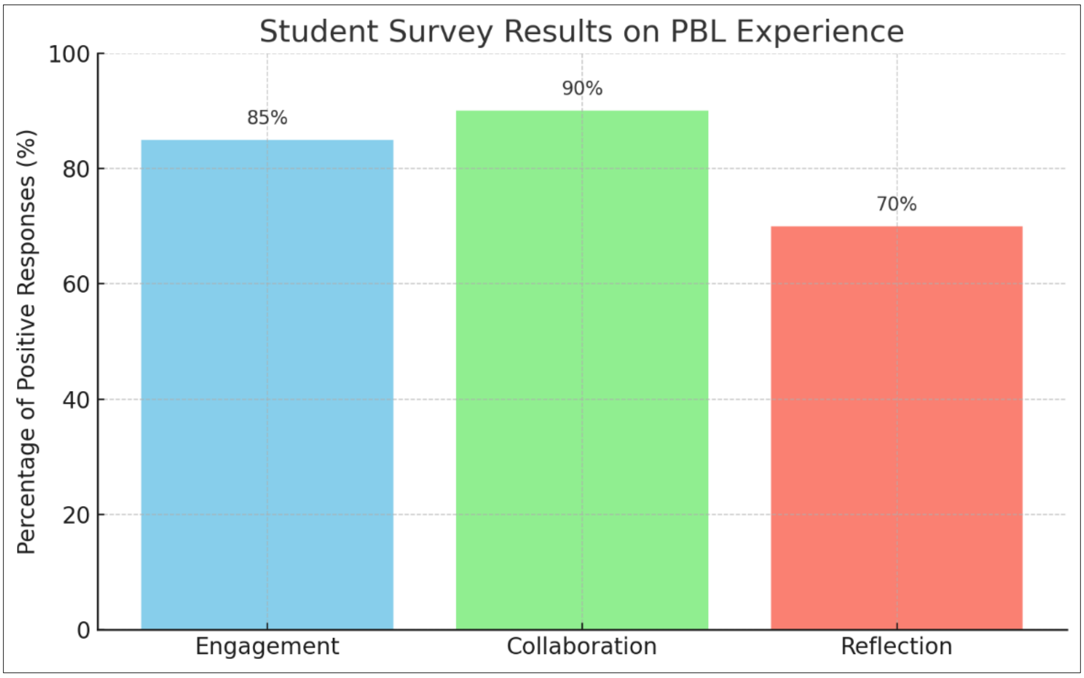


Qualitative Findings

Student Reflections

Thematic analysis of 33 student reflection surveys identified recurring themes: ownership of learning, enjoyment of collaboration, and increased confidence in problem-solving. One student noted, "This was the first time I felt like I was building something meaningful, not just doing assignments", "Completed school projects in time and good teamwork established with teammates" and "my teammates and I presented confidently in front of our classmates." These reflections affirm the motivational and developmental benefits of PBL.

Figure 2: Student Survey Results on PBL Experience



Based on Figure 2, the student survey responses indicated a generally positive perception of the Project-Based Learning (PBL) experience. Engagement received an 85% positive response rate, suggesting that students found the PBL activities motivating and stimulating. This aligns with previous findings by Rizwan et al. (2021), who emphasized that PBL increases learner agency and interest in computing through real-world tasks. Collaboration received the highest positive feedback at 90%, reflecting the effectiveness of team-based projects in enhancing communication, cooperation, and joint problem-solving skills. These findings resonate with Dema and Choden (2024), who reported that structured collaborative learning within PBL environments fosters deeper understanding and peer-driven knowledge construction, especially for gifted learners.

However, reflection, while still relatively high at 70%, was rated lower than the other two dimensions. This result points to a potential area for improvement in embedding structured reflection and metacognitive activities into PBL cycles. As Koppel (2018) and Stanley (2021) noted, reflective assessment is vital for promoting long-term retention and deeper learning—particularly for high-ability students who benefit from metacognitive growth.

Qualitative responses from students further supported these trends. Many noted that PBL helped them connect abstract computing concepts to practical applications, but some expressed a need for more structured feedback and self-evaluation opportunities. This suggests that while the collaborative and engaging nature of PBL is well received, more intentional incorporation of reflective practices may enhance overall effectiveness.

These findings affirm that PBL is a highly suitable pedagogical approach for gifted and talented students in computer science, especially when scaffolded to support deeper cognitive engagement and personal learning pathways. The results also provide actionable insight for educators seeking to optimize PBL implementations for high-ability learners.

DISCUSSION

The findings of this study indicate that Project-Based Learning (PBL) has a substantial positive impact on problem-solving skills, and long-term learning outcomes among gifted and talented students in Computer Science. These results reinforce and extend the conclusions of earlier research that suggested PBL enhances motivation and cognitive engagement (Helle et al., 2020; Rizwan et al., 2021), particularly when learning is structured around meaningful, real-world tasks.

Consistent with previous research (Stanley, 2021), the data indicates that PBL supports the development of advanced problem-solving skills. Students demonstrated increased ability to structure problems, apply computational logic, and collaborate effectively in teams. These outcomes are especially relevant in the context of computer science education, where hands-on experience and iterative thinking are core competencies. Gifted students appeared to benefit from the opportunity to tackle complex tasks requiring higher-order thinking and creative approaches.

Long-term retention of concepts is another indicator of effective learning design. The high retention rates among students suggest that the integration of active, project-based methods reinforces durable understanding of computing principles. This supports findings by Koppel (2018) that long-term learning is enhanced when students engage in reflection and application rather than rote memorization.

While the benefits of PBL were evident, challenges related to task difficulty and pacing emerged. Some gifted students desired more advanced or customized tasks, indicating that even high-performing learners require differentiated support. This highlights the need for careful scaffolding and ongoing formative assessment to ensure that all students remain challenged at appropriate levels. Furthermore, managing group dynamics and ensuring equitable contribution among peers remain areas of consideration for educators implementing PBL with high-ability learners.

The study’s findings suggest that when thoughtfully designed, PBL can serve as a highly effective pedagogical approach for gifted learners in computing. Educators should consider incorporating structured reflection, opportunities for advanced exploration, and flexibility in project design to maximize the benefits of PBL. Moreover, teacher training in differentiated instruction within project-based contexts may be key to addressing the diverse needs of gifted students.

Limitations

Several limitations should be considered when interpreting the findings. First, the study was conducted with 46 students from a single gifted-education setting and used purposive sampling. The contextual nature of the sample limits the generalizability of the findings to other gifted learners, school systems, and computing programmes. Future studies should incorporate larger and more diverse samples across different gifted-education contexts to strengthen external validity.

Second, the study did not include a control or comparison group. Consequently, the observed increase in PBL assessment performance cannot be attributed causally to PBL alone. Differences in project phase, content, assessment requirements, prior learning, or other instructional factors may have contributed to the observed pattern. Future research could employ quasi-experimental or longitudinal designs with comparison conditions to strengthen causal inference. Third, individual peer-evaluation records were unavailable, limiting the analysis to aggregate descriptive statistics.

Future Research and Implications

Future iterations of this research should incorporate larger and more diverse samples across different gifted-education contexts to strengthen external validity and the transferability of findings. Comparative studies involving different schools, programmes, and learner populations could provide further evidence regarding the applicability of PBL across educational contexts.

Future PBL implementations should also embed structured reflection activities at key stages of the project, such as guided learning journals, peer-feedback loops, and metacognitive prompts. These activities could provide systematic opportunities for students to monitor their learning, evaluate problem-solving strategies, and articulate how their understanding develops over time.

Differentiation should be explicitly incorporated into project design. Future projects could provide tiered requirements, optional extension challenges, flexible inquiry pathways, or individualized project components so that gifted learners can experience appropriate intellectual challenge while working toward common learning outcomes. This is particularly relevant to multi-semester PBL implementations, where maintaining challenge and engagement may become increasingly difficult.

Future studies should examine group dynamics and equitable participation more systematically. Retaining individual peer-evaluation data and combining them with structured observation, individual contribution records, and group-process measures could provide richer evidence concerning role distribution, communication, leadership, negotiation, and participation patterns during collaborative problem-solving.

Finally, future project tasks should maintain strong connections to authentic computing applications. Projects involving data analysis, intelligent systems, software development, IoT, or community-based digital solutions may provide opportunities for students to transfer computational knowledge to meaningful contexts. Future research should examine whether such authentic applications influence motivation, knowledge transfer, and conceptual understanding over longer periods, using appropriate delayed measures where retention is a specific research objective.

CONCLUSION

This study examined PBL within a gifted secondary Computer Science context involving 46 students undertaking extended computing projects across two semesters. The quantitative findings showed a significant increase in PBL assessment performance from Semester 1 to Semester 2, while the phase-level analysis demonstrated that performance varied across the four project phases. Peer-evaluation results showed a small descriptive increase and lower variability in Semester 2, while student reflections and classroom observations indicated generally positive experiences of engagement and collaboration and observable collaborative behaviours during project activities.

The findings provide evidence that PBL can serve as a meaningful context for applied learning and collaborative activity among gifted Computer Science learners. However, the study does not establish that PBL alone caused the observed improvement, nor does semester-level performance constitute a direct measure of long-term knowledge retention. The lower positive response for reflection also highlights an opportunity to strengthen structured metacognitive activities within future PBL cycles.

Overall, the study suggests that PBL for gifted learners is most appropriately viewed not simply as the use of projects, but as a learning design that combines authentic computing problems with collaboration, differentiated challenge, learner reflection, and appropriate assessment. Future research should extend this work through larger and more diverse samples, stronger comparison designs, more systematic analysis of group dynamics, and structured reflection and retention measures.

ACKNOWLEDGMENT

The authors would like to acknowledge the support provided by PERMATA@Pintar National Gifted Centre National University for research facilities and resources. Appreciation is also extended to all individuals who offered valuable feedback and suggestions that contributed to the improvement of this article.

REFERENCES

1. Abdull Jabbar, R., & Abd Halim, N. D. (2024). The impact of Project-Based Learning through integrating the use of technology in Computer Science courses on students' acquisition of programming skills. Innovative Teaching and Learning Journal, 8(1), 1–14. https://doi.org/10.11113/itlj.v8.152
2. Baccassino, F., & Pinnelli, S. (2023). Giftedness and gifted education: A systematic literature review. Frontiers in Education, 7, 1073007. https://doi.org/10.3389/feduc.2022.1073007
3. Bunyamin, B. (2023). Internet of Things for Project-Based Learning in "Vocational High School Building Village Program". JINoP (Jurnal Inovasi Pembelajaran), 9(2), 246–259. https://doi.org/10.22219/jinop.v9i2.26322
4. Collaguazo, A., Villavicencio, M., & Abran, A. (2023). An activity-based approach for the early identification and resolution of problems in the development of IoT systems in academic projects. Internet of Things, 24, 100929. https://doi.org/10.1016/j.iot.2023.100929

5. Dema, C., & Choden, U. (2024). Impact of Project-Based Learning on Computer Science Education. Educational Innovation and Practice, 7(1), 29–54. https://doi.org/10.17102/eip.7.2024.08
6. Guo, L. (2022). How should reflection be supported in higher education? A meta-analysis of reflection interventions. Reflective Practice, 23(1), 118–146. https://doi.org/10.1080/14623943.2021.1995856
7. Guo, P., Saab, N., Post, L. S., & Admiraal, W. (2020). A review of project-based learning in higher education: Student outcomes and measures. International Journal of Educational Research, 102, 101586. https://doi.org/10.1016/j.ijer.2020.101586
8. Lee, D. H. (2022). Case study on the mathematically gifted elementary students' collaborative mathematical problem solving. Journal of Science Education for the Gifted, 14(3), 164–174.
9. Li, W., Liu, C.-Y., & Tseng, J. C. R. (2024). Development of a metacognitive regulation-based collaborative programming system and its effects on students' learning achievements, computational thinking tendency and group metacognition. British Journal of Educational Technology, 55(1), 318–339. https://doi.org/10.1111/bjet.13358
10. Nicholas, M., Skourdoumbis, A., & Bradbury, O. (2024). Meeting the needs and potentials of high-ability, high-performing, and gifted students via differentiation. Gifted Child Quarterly, 68(2), 154–172. https://doi.org/10.1177/00169862231222225
11. Ouyang, F., Xu, W., & Cukurova, M. (2023). An artificial intelligence-driven learning analytics method to examine the collaborative problem-solving process from the complex adaptive systems perspective. International Journal of Computer-Supported Collaborative Learning, 18, 39–66. https://doi.org/10.1007/s11412-023-09387-z
12. Saad, A., & Zainudin, S. (2022). A review of Project-Based Learning (PBL) and Computational Thinking (CT) in teaching and learning. Learning and Motivation, 78, 101802. https://doi.org/10.1016/j.lmot.2022.101802
13. Tibken, C., Richter, T., von der Linden, N., Schmiedeler, S., & Schneider, W. (2022). The role of metacognitive competences in the development of school achievement among gifted adolescents. Child Development, 93(1), 117–133. https://doi.org/10.1111/cdev.13640
14. Zhang, W., Guan, Y., & Hu, Z. (2024). The efficacy of project-based learning in enhancing computational thinking among students: A meta-analysis of 31 experiments and quasi-experiments. Education and Information Technologies, 29, 14513–14545. https://doi.org/10.1007/s10639-023-12392-2