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Effectiveness of Technology-Assisted Project-Based Learning Model in Teaching Blood Inventory Management Principles to Blood Bank Technology Students

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ABSTRACT This study investigates the effectiveness of a Technology-Assisted Project-Based Learning (TAPBL) model in teaching blood inventory management to undergraduate students in a Blood Bank Technology program. Using a quasi-experimental design, the study compared outcomes between a control group (traditional lectures) and an intervention group (TAPBL). Quantitative data were gathered through pre- and post-tests, while qualitative insights were derived from focus group discussions and reflective journals. The TAPBL group demonstrated significantly higher academic performance, with a mean post-test score improvement of 25.3 points versus 10.3 in the control group. ANCOVA results confirmed the instructional model had a statistically significant effect on learning gains. A Likert-scale survey revealed that over 90% of TAPBL students agreed that digital tools improved understanding and engagement. Thematic analysis highlighted four key benefits of TAPBL: authentic learning, collaborative problem-solving, digital fluency, and reflective practice. Students reported enhanced motivation, real-world relevance, and stronger teamwork and decision-making skills. The integration of simulations and cloud-based tools allowed learners to manage virtual inventories, forecast blood needs, and analyze stock issues. This approach effectively bridges the gap between theoretical concepts and practical applications. These findings suggest that TAPBL is a powerful and scalable pedagogical model for modernizing transfusion education. It not only enhances cognitive learning but also supports professional skill development and engagement, aligning well with Competency-Based Education (CBE) goals. This research provides empirical evidence that TAPBL can significantly improve the quality of blood bank education and help prepare students for the complexities of real-world healthcare environments.

Keywords: Blood inventory management, Health sciences, Project-based learning, Simulation-based learning, Technology-assisted learning, Transfusion education

1. INTRODUCTION

Blood inventory management stands as one of the most vital pillars of operational effectiveness in transfusion medicine (Najafi et al., 2017). It involves a complex orchestration of logistical, clinical, and administrative practices aimed at ensuring the availability, accessibility, and optimal use of various blood components, including red blood cells (RBCs), platelets, plasma, and cryoprecipitates (Sahid Ramadhan et al., 2019). These components are indispensable in diverse clinical settings, from trauma resuscitation and major surgeries to hematologic disorder treatments and obstetric emergencies. A failure in blood inventory systems, either due to understocking, overstocking, or poor forecasting (Thakur, 2024), can lead to dire consequences: patient morbidity and mortality, massive wastage of blood products due to expiration, or increased costs from emergency procurement (Setwaba, 2022).

While most hospitals have protocols for managing blood stocks, many continue to experience recurring challenges (WHO, 2023b). Seasonal fluctuations in donor availability, unpredictable demand surges during public health emergencies, and the short shelf life of platelets and thawed plasma necessitate dynamic, data-driven inventory

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strategies. Blood bank professionals are expected not only to understand standard operating procedures but also to possess robust analytical and decision-making competencies. Thus, the educational preparation of these professionals must include both technical mastery and practical readiness in inventory handling (Astuti et al., 2021).

However, despite the strategic significance of this domain, educational strategies in blood bank technology remain predominantly didactic (Filetti & Saso, 2020). Many training programs still rely on lecture-based formats and passive knowledge transmission, offering limited opportunities for learners to engage in authentic problem-solving or apply their understanding in operational contexts. This is especially problematic in a field where on-the-ground decisions, such as redistributing units nearing expiry or determining reorder points, carry direct implications for patient safety and institutional efficiency (Doherty, 2024).

In response to the limitations of traditional pedagogical models, there has been a global shift toward learner-centered approaches that emphasize active, experiential learning. Within this landscape, Project-Based Learning (PBL) has garnered significant attention. Rooted in constructivist learning theories, PBL empowers students to engage in extended inquiry around complex questions or challenges (Wright & Wright, 2023). Learners work collaboratively, assume roles, research authentic problems, and produce tangible outputs. This methodology has been widely adopted in disciplines such as engineering, business, and medicine, showing notable improvements in knowledge retention, critical thinking, collaboration, and motivation (Filetti & Saso, 2020).

In the context of blood inventory management, PBL offers immense potential. Simulated scenarios involving stockouts, over-ordering, demand forecasting, and logistical constraints could serve as ideal projects, enabling students to internalize core inventory principles while honing decision-making skills. Yet, despite this promise, the integration of PBL into the niche domain of blood bank education, particularly within Southeast Asia, remains under-explored in both practice and literature (Yulisma et al., 2023).

Adding a further layer of innovation is the incorporation of technology-assisted learning tools into the PBL framework. The advent of Technology-Assisted Project-Based Learning (TAPBL) introduces digital platforms that can enhance project collaboration, simulate real-time inventory dashboards, visualize supply-demand trends, and allow access to electronic Blood Management Systems (eBMS) or Hospital Information Systems (HIS) (Kldiashvili et al., 2025). Students may also use analytics software to interpret usage patterns, predict shortages, and propose solutions. These digital augmentations are not only engaging but also mirror the tools and systems used in actual clinical practice, creating a more authentic and relevant learning experience (Doherty, 2024).

TAPBL holds particular promise in addressing the often-cited challenge of bridging the theory-practice gap in health sciences education. While theoretical understanding of inventory models (e.g., FIFO, LIFO, Just-In-Time, Min-Max systems) is essential, application in live environments requires nuanced judgment, contextual sensitivity, and collaboration with multidisciplinary teams (Rahmah & Chairunnissa, 2021). By working through real-world case studies, such as planning inventory for a blood drive during dengue season or analyzing platelet wastage trends, students in TAPBL environments can gain practical insights and confidence in executing professional roles (Chien et al., 2025).

Importantly, TAPBL also aligns with Competency-Based Education (CBE) frameworks now being adopted across medical and allied health education. CBE emphasizes demonstrable skills and outcomes rather than time-based progression, making TAPBL an ideal modality for fostering key competencies such as leadership in crisis, communication during stock imbalances, and data-driven decision-making (Alharbi, 2024). As future transfusion professionals are expected to navigate increasingly complex clinical environments, educational reforms incorporating TAPBL can contribute meaningfully to their preparedness (Freddie et al., 2024).

Furthermore, student engagement remains a critical metric in evaluating the effectiveness of any educational innovation. Research has consistently shown that learners exposed to interactive, technology-driven modalities report higher levels of motivation, autonomy, and satisfaction (Kldiashvili et al., 2025). Engagement is particularly crucial in technical fields like blood banking, where perceived relevance and immediate applicability can drive deeper investment in learning tasks. By incorporating technology-enabled collaboration, feedback loops, and simulated risk assessments, TAPBL may significantly enhance the affective domain of student learning alongside cognitive and psychomotor outcomes (Filetti & Saso, 2020; Yulisma et al., 2023).

Despite the theoretical robustness of TAPBL and its promising results in other fields, empirical investigations specifically evaluating its impact in blood bank education remain scarce (Yulisma et al., 2023). Preliminary reports suggest improvements in decision-making and teamwork among students exposed to TAPBL in laboratory medicine settings, but rigorous, outcome-oriented research in the context of blood inventory education is needed. This lack of domain-specific evidence constitutes a significant research gap and an opportunity for innovation in curriculum design (Doherty, 2024).

While Project-Based Learning (PBL) has been widely implemented in general medical education, its application in the highly specialized field of blood bank technology,

specifically concerning the logistical complexities of blood inventory management, remains under-researched. Previous studies often focus on clinical skills, yet there is a significant gap in understanding how technology-assisted PBL (TAPBL) can bridge the gap between theoretical inventory theory and real-world supply chain pressures. This study uniquely integrates the 'SimTransfuse' simulation platform with cloud-based collaboration to foster not only cognitive gains but also professional competencies such as decision-making under scarcity.

This study is thus designed to systematically evaluate the implementation of a TAPBL model in teaching blood inventory management to students enrolled in a diploma or undergraduate program in Blood Bank Technology. The research focuses on three primary outcomes: (1) improvement in cognitive understanding of inventory management principles; (2) enhancement of decision-making and problem-solving skills; and (3) increased student engagement and motivation. Using a quasi-experimental design with mixed methods (quantitative pre-post testing and qualitative thematic analysis), the study offers a comprehensive assessment of TAPBL's pedagogical effectiveness.

Moreover, the study carries broader implications for health sciences education in developing countries. As educational institutions in regions like Southeast Asia seek to modernize training programs in response to evolving workforce demands, evidence-based innovations such as TAPBL can inform national curriculum reforms and accreditation standards. The digital component also allows for scalability, enabling institutions with limited laboratory capacity to simulate real-time inventory situations, thereby reducing costs without compromising on educational quality. Therefore, the central problem addressed in this research is whether the integration of digital simulation within a PBL framework can effectively address the pedagogical limitations of traditional lectures in blood inventory education.

In conclusion, the urgency to modernize blood bank education, especially in operationally intensive areas like inventory management, is undeniable. As clinical environments become more data-driven and technology-enabled, so too must educational strategies evolve to produce competent, confident, and adaptive professionals. TAPBL presents a powerful, integrative approach that not only addresses pedagogical gaps but also aligns with the future of transfusion medicine. Through this research, we seek to contribute empirical evidence and practical insights into how TAPBL can transform the learning experience in blood bank technology programs, ultimately improving the quality of patient care.

2. METHOD

2.1 Objectives

The primary objectives of this study are to assess the impact of TAPBL on students' understanding of blood inventory management principles, compare the learning outcomes between students exposed to TAPBL and those undergoing traditional instruction, evaluate students' engagement, collaboration, and problem-solving skills within a TAPBL environment, identify the strengths and limitations of implementing TAPBL in blood bank education, examine students' perceptions of usability and effectiveness of digital tools used in TAPBL, and provide recommendations for the integration of TAPBL in blood bank curricula across similar institutions (Filetti & Saso, 2020; Yulisma et al., 2023).

2.2 Research Design

This study employed a quasi-experimental design with a mixed-methods approach. A combination of pre- and post-tests was used to measure knowledge acquisition, while qualitative tools such as focus group discussions, observation checklists, and reflective journals captured learner experiences and perceptions (Doherty, 2024).

2.3 Participants

Participants consisted of 64 undergraduate students enrolled in a Blood Bank Technology program at a public university specializing in health sciences. Inclusion criteria required that students had completed preliminary coursework in transfusion medicine. They were randomly assigned to two groups: the control group and the intervention group, each comprising 32 students. The control group received conventional lecture-based instruction, while the intervention group was engaged in a TAPBL module.

2.4 Intervention (TAPBL Implementation)

The intervention spanned eight weeks and consisted of carefully structured modules integrating project-based tasks with digital tools. Students in the intervention group were divided into teams and assigned a series of case-based projects simulating real-life blood inventory challenges, including shortage forecasting, stock rotation, expiry tracking and disposal, donor blood utilization, and contingency planning in emergencies (Bates & Owusu-Ofori, 2020; Najafi et al., 2017; WHO, 2023a). Each team was required to use project management software such as Trello, cloud-based spreadsheets like Google Sheets, and inventory simulation platforms, including SimTransfuse. The SimTransfuse platform used in this study is a specialized educational software designed to replicate blood bank inventory dynamics. It allows students to engage with shelf-life tracking, ABO/Rh compatibility forecasting, and emergency stock depletion scenarios in a risk-free virtual environment. This tool serves as the primary simulation interface where students apply theoretical inventory models to solve real-world logistical challenges (Zhang et al., 2021). Faculty mentors provided

periodic feedback through weekly checkpoints, guiding the teams in project execution while allowing students to independently manage tasks and make data-driven decisions.

2.5 Data Collection

Quantitative data were collected through pre-and post-tests consisting of 40 multiple-choice questions designed to assess knowledge of inventory concepts such as reorder points, shelf-life, supply chain coordination, and emergency stock handling. Qualitative data were gathered via focus group discussions, weekly journal entries, and faculty observations (Koo & Yang, 2025). The focus group discussions were conducted in the ninth week, following the completion of the project modules, using structured open-ended questions to elicit detailed responses on student experiences (Baidoo et al., 2024). Additionally, a Likert scale survey was administered at the end of the study to measure student engagement, satisfaction, and perceived learning outcomes in the TAPBL environment (Koo & Yang, 2025).

2.6 Data Analysis

Quantitative data were analyzed using Jeffreys's Amazing Statistics Program (JASP) version 18 to ensure objective validation of the instruments, the inter-rater reliability was calculated using Cohen's Kappa coefficient, resulting in a score of 0.82, indicating a high level of agreement between validators. Paired sample t-tests were employed to compare pre- and post-test scores within each group, and ANCOVA was utilized to examine the differences between post-test results across groups, while controlling for baseline performance (Rosdiana, 2019). The results were interpreted to determine the significance and magnitude of TAPBL's impact on cognitive learning. Qualitative data from focus group discussions and journal entries were transcribed, coded, and thematically analyzed using NVivo software (Priyatni et al., 2020). Emergent codes were clustered into overarching themes, including collaboration, practical understanding, technology usability, motivation, and knowledge retention, allowing for triangulation of data and an in-depth understanding of student perspectives.

2.7 Strengths and Limitations

One of the strengths of this study lies in its blended methodology, which combines objective assessment tools with qualitative insights to offer a comprehensive evaluation of TAPBL. The use of authentic and practical projects enhances ecological validity, as students engage with scenarios that mirror real clinical situations. Moreover, the integration of modern digital tools reflects the operational realities of contemporary blood banks, increasing the relevance and transferability of skills acquired. However, the study also has limitations. The findings may not be generalizable beyond the single-institution context, and the short duration of the intervention may not fully capture long-term knowledge retention or skill development. Additionally, despite efforts to standardize evaluation criteria, potential for instructor bias exists, and disparities in digital literacy among students may have influenced outcomes.

3. RESULT

The present study employed a quasi-experimental design with a control group (n=32) and an intervention group (n=32) to investigate the effects of the Technology-Assisted Project-Based Learning (TAPBL) model on students' academic performance and engagement in learning blood inventory management. The analysis combined quantitative (pre-posttest, ANCOVA, and Likert scale survey) and qualitative (reflective journals and focus group discussions) data to provide a comprehensive assessment of learning outcomes.

3.1 Academic Performance: Pre- and Post-Test Results

At baseline, both groups demonstrated comparable levels of theoretical understanding of blood inventory management, as evidenced by statistically non-significant differences in pre-test scores ($p>0.05$). As shown in Table 1, the mean pre-test score for the control group was 61.8 ($SD=7.2$), while the TAPBL group averaged 62.3 ($SD=7.1$). An independent samples t-test confirmed that there was no significant difference between the groups prior to the intervention, indicating that the groups were homogeneous in terms of foundational knowledge.

Following the eight-week instructional intervention, significant improvements were observed in both groups; however, the TAPBL group exhibited markedly superior academic gains. The mean post-test score in the control group increased to 72.1 ($SD=7.8$), resulting in a mean gain of +10.3 points. In contrast, the TAPBL group's post-test score surged to 87.6 ($SD=6.4$), representing a substantial mean gain of +25.3 points.

Paired sample *t*-tests confirmed statistically significant improvements within both groups ($p=0.041$ for control, $p<0.001$ for TAPBL), but the magnitude of improvement was more than double in the intervention group. Furthermore, an ANCOVA controlling for pre-test scores revealed a statistically significant effect of the instructional

Table 1 Comparison of Pre-test and Post-test Scores Between Control and TAPBL Groups

Groups	Mean Pre-test (SD)	Mean Post-test (SD)	Mean Gain	*p*-value (Paired t-test)
Control (n=32)	61.8 (7.2)	72.1 (7.8)	+10.3	0.041
TAPBL (n=32)	62.3 (7.1)	87.6 (6.4)	+25.3	<0.001

Note: ANCOVA Result (controlling for pre-test): $F(1,61)=22.54$, $p<0.001$

model on post-test outcomes ($F(1,61)=22.54$, $p<0.001$), establishing TAPBL as a more effective teaching method in this context.

3.2 Learning Gains by Topic Area

Further item analysis of the post-test revealed that TAPBL students outperformed their peers across multiple cognitive domains, including: (1) forecasting blood demand, (2) optimizing stock rotation policies, and (3) interpreting transfusion thresholds. The largest improvements were seen in case-based questions requiring multidimensional decision-making, suggesting that TAPBL's integrative and contextual learning approach better supports higher-order cognitive development.

3.3 Engagement and Satisfaction: Quantitative Survey Results

To assess the affective dimension of learning, a post-intervention engagement survey was administered to the TAPBL group. The key assessment areas evaluated in this survey are summarized in Table 2. The survey employed a 5-point Likert scale covering five key areas: (1) perceived enhancement of understanding through digital tools, (2) applicability of theoretical knowledge, (3) learning engagement, (4) teamwork and communication, and (5) willingness to recommend TAPBL. Results indicated overwhelmingly positive perceptions. Over 90% of students agreed or strongly agreed that the integration of digital tools, such as cloud-based inventory simulations and project dashboards, improved their comprehension of blood inventory concepts. Similarly, 87.5% agreed that project-based tasks helped contextualize theoretical knowledge. Additionally, a substantial majority reported enhanced teamwork, communication, and time management skills.

3.4 Thematic Analysis: Qualitative Insights

To gain a deeper understanding of students' learning experiences, a thematic analysis was conducted using qualitative data derived from reflective journals (n=32) and two focus group discussions (each consisting of eight students from the intervention group). The qualitative data were transcribed, coded, and analyzed using NVivo software, allowing for systematic identification of recurring patterns and themes. The analysis revealed four dominant themes that provide valuable insights into how the TAPBL model influenced students' cognitive, behavioral, and emotional engagement.

The first major theme that emerged was the authenticity of learning. Many students emphasized that the project-based activities, which simulated real-world scenarios in blood inventory management, made the subject matter more engaging and meaningful. They reported that working on actual problems, such as managing expired stock, forecasting supply during peak demands, or planning for emergencies, helped them better understand the stakes and complexity of real transfusion services. One student expressed, "I felt like I was actually managing an inventory system, not just learning about it," illustrating how the immersive nature of the projects translated into a deeper personal investment in the learning process.

The second prominent theme was collaborative problem-solving. Students reported that working in teams on complex, open-ended tasks significantly improved their communication and interpersonal skills. They highlighted that the group-based format necessitated the division of responsibilities, which led to more effective role delegation, mutual accountability, and peer learning. Through regular group discussions and shared decision-making, students not only advanced their understanding of the subject but also developed essential soft skills such as negotiation, leadership, and time management. Many students stated that the collaborative nature of the projects mirrored real hospital workflows, where interdisciplinary teamwork is a critical component of daily operations.

A third theme that emerged was digital fluency and technological empowerment. Students consistently reflected on their experiences using digital tools such as SimTransfuse, cloud-based spreadsheets, and collaborative dashboards. Although several students initially found the technology challenging, most eventually saw these tools as empowering resources that enhanced their learning. They reported increased confidence in interpreting digital data, managing online project timelines, and using simulations to test their decisions. Moreover, many students noted that the technological components made the learning process more dynamic and allowed for continuous feedback, which

Table 2 Student Engagement and Satisfaction in TAPBL Group (Likert Scale Results)

Statement	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
Digital tools enhanced my understanding of blood inventory management	53.1	37.5	9.4	0.0	0.0
Project-based tasks helped me apply theoretical knowledge to real cases	50.0	37.5	12.5	0.0	0.0
I felt more engaged in the learning process	59.4	28.1	12.5	0.0	0.0
Teamwork improved my communication and collaboration skills	62.5	25.0	12.5	0.0	0.0
I would recommend TAPBL for future courses	68.8	21.9	9.4	0.0	0.0

further deepened their understanding of blood inventory principles and clinical relevance.

The fourth and final theme was reflective practice, which highlighted the value students placed on structured reflection throughout the intervention. The reflective journals, completed weekly, served as spaces for students to document their thought processes, evaluate their progress, and identify areas for improvement. Several students indicated that journaling encouraged them to think critically about their learning journey, articulate their challenges, and take ownership of their performance. This metacognitive engagement appeared to reinforce both self-awareness and professional development, as students became more attuned to the decision-making demands of blood bank operations.

Overall, the thematic analysis of the qualitative data suggests that TAPBL not only enhanced students' academic understanding but also fostered the development of essential transfusion-related professional competencies. These findings align with the quantitative outcomes and provide a more nuanced account of how the intervention cultivated authentic, collaborative, and reflective learning environments supported by technological integration (Figure 1).

3.5 Synthesis of Quantitative and Qualitative Findings

The quantitative results, which showed a significant increase in post-test scores ($p < 0.05$), are strongly supported by the qualitative themes extracted from student reflections. For instance, the 'Authentic Learning' theme explains why cognitive scores improved: students reported that the SimTransfuse simulation made abstract concepts of 'inventory turnover' tangible. The synergy between statistical gains and student experiences suggests that TAPBL doesn't just help students memorize facts but allows them to internalize the operational logic of a blood bank. This integration of data confirms that the technology-assisted model effectively bridges the gap between theoretical knowledge and practical application.

By triangulating quantitative and qualitative data, this study substantiates that TAPBL not only facilitates cognitive advancement as indicated by post-test scores but also enhances engagement, professional readiness, and learner autonomy. These outcomes are essential for the development of competent transfusion professionals who are expected to operate under pressure, make data-driven decisions, and collaborate across interdisciplinary teams.

4. DISCUSSION

This study set out to examine whether a Technology-Assisted Project-Based Learning (TAPBL) model could enhance the learning outcomes of undergraduate students enrolled in a Blood Bank Technology program, specifically in the area of blood inventory management. The findings offer robust evidence that TAPBL contributes not only to improved cognitive performance but also to a transformative educational experience, one that fosters student engagement, practical skill development, and professional confidence, all of which are essential in contemporary healthcare environments (Cabero-Almenara et al., 2023).

A key finding of this research is the marked improvement in academic performance among students who participated in the TAPBL intervention. Compared to their peers in the control group, who received conventional lecture-based instruction, students in the TAPBL group demonstrated significantly greater post-test score gains (Elkhamisy et al., 2022). While both groups exhibited improvement, the magnitude of change in the TAPBL cohort was considerably higher, suggesting a deeper and more sustained understanding of the concepts involved. This difference is not trivial; it reflects a substantial shift in learning outcomes attributable to the instructional model, thereby reinforcing the pedagogical strength of TAPBL in delivering complex, practice-oriented content (Hujjatusnaini et al., 2022).

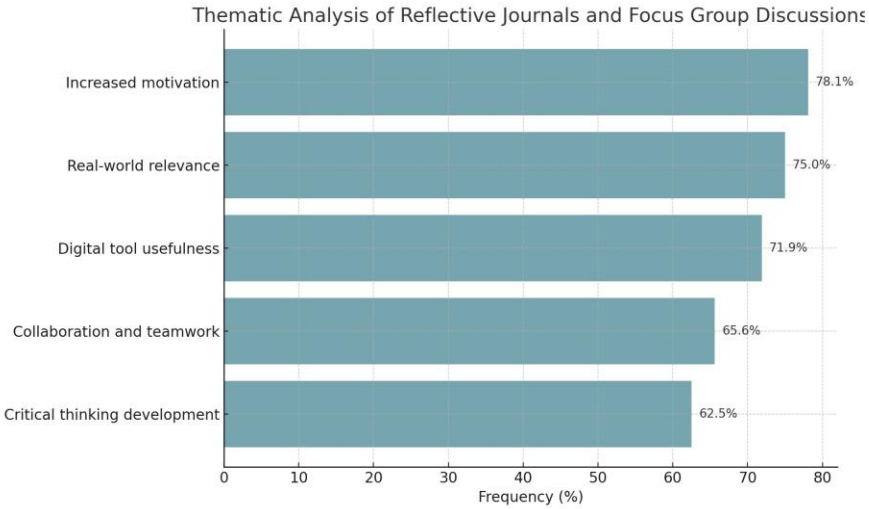

Figure 1 Conceptual Framework of Student Engagement Themes in SimTransfuse Platform

Fundamentally, TAPBL places learning within an authentic and purposeful context. Students are not passive recipients of static information; rather, they are active participants tasked with solving dynamic, real-world problems. Within this framework, students were required to manage simulated blood inventory systems, forecast supply and demand, and make difficult resource allocation decisions (Pranjol et al., 2024). For many participants, this shift in instructional approach was both intellectually stimulating and personally empowering. They were compelled to engage not only with theoretical knowledge but also with its real-world implications. Even within a simulated environment, the consequences of their decisions carried weight, and this authenticity appeared to foster a heightened sense of responsibility and self-directed learning. Several students reported feeling more accountable for their understanding, as their roles in simulation activities closely resembled those of actual healthcare professionals (Lee et al., 2024; L. Zhang & Ma, 2023).

Furthermore, the cognitive demands of the TAPBL tasks encouraged the development of higher-order thinking skills. Blood inventory management is inherently complex, involving real-time decision-making related to expiration dates, variable demands, critical shortages, and wastage prevention. These challenges require more than rote memorization; they demand analysis, prioritization, and predictive reasoning. The learning tasks were intentionally designed to cultivate these competencies. This was clearly reflected in the data, as students in the TAPBL group performed better on assessments that measured application, synthesis, and evaluation, core indicators of advanced cognitive processing, rather than mere recall.

Equally significant are the gains observed in the affective and interpersonal domains of learning. Many students described the TAPBL learning environment as highly engaging, collaborative, and aligned with the realities of clinical practice. The presence of real-world relevance and a clear sense of purpose embedded in each project appeared to enhance students' intrinsic motivation. Learning ceased to be an abstract academic exercise and became a preparation for genuine professional responsibility. This shift in perception catalyzed a deeper commitment to the learning process and a stronger connection to the subject matter (Cabero-Almenara et al., 2023; Sedayu et al., 2024).

Collaboration emerged as one of the most impactful components of the TAPBL experience. In contrast to traditional instructional settings, where students often work individually or in isolation, TAPBL necessitated regular interaction, cooperation, and collective problem-solving. Students were required to communicate effectively, distribute tasks equitably, and reach consensus on complex issues such as prioritizing blood product distribution or managing inter-institutional stock variation (Elkhamisy et al., 2022). In doing so, they developed both technical proficiency and critical interpersonal skills. These included active listening, delegation, negotiation, and team leadership skills that are not ancillary but fundamental to functioning within interdisciplinary healthcare environments. Students consistently reported that these collaborative experiences felt authentic and closely mirrored the team-based dynamics they expect to encounter in professional settings (Hujjatusnaini et al., 2022).

Technology served as an essential enabler of the TAPBL model. The use of digital platforms, including cloud-based spreadsheets, collaborative dashboards, and inventory simulation software, provided a structured yet flexible learning environment. While a small number of students initially experienced difficulties in navigating these tools, the majority quickly adapted and ultimately found them to be both engaging and empowering (Pranjol et al., 2024). Through repeated exposure and guided application, students became proficient in managing digital data, visualizing stock trends, and simulating inventory fluctuations in response to changing demand. Importantly, they also developed a broader form of digital literacy, which is increasingly recognized as a vital skill in healthcare systems characterized by electronic records, automated logistics, and data-driven decision-making (Lee et al., 2024).

A particularly noteworthy element of the TAPBL experience was the emphasis on reflective practice. Through weekly journaling and guided discussions, students were encouraged to engage in metacognitive analysis to consider not only what they were learning, but how and why they were learning it. Many students expressed that this process significantly enhanced their capacity for self-evaluation and independent learning. It enabled them to identify both strengths and weaknesses in their approach and to take deliberate steps toward improvement (Zhang & Ma, 2023). Reflective writing also helped some students articulate their evolving understanding of the ethical and logistical complexities involved in managing life-critical resources such as blood products. In this regard, the inclusion of structured reflection added depth to the educational experience and contributed to students' professional identity formation. Taken together, these findings suggest that TAPBL cultivates a learning environment that is not only academically effective but also developmentally meaningful. It shifts the role of students from passive knowledge recipients to engaged learners and emergent professionals. Students become more confident, more inquisitive, and more prepared to embrace the multifaceted challenges inherent in blood bank operations and clinical logistics (Baidoo et al., 2024; Sedayu et al., 2024).

By contrast, the experiences of students in the control group, while not without merit, appeared more constrained. Though they achieved moderate academic gains and

acknowledged the clarity of traditional lectures, many reported difficulties in relating abstract content to practical application. The absence of contextualized tasks and interactive learning opportunities limited the depth and relevance of their educational experience (Muthivhi et al., 2015). Several students described the material as repetitive or disconnected from real-life scenarios. These responses highlight the limitations of conventional lecture-based pedagogy, particularly when teaching operationally complex subject matter. While lectures remain useful for conveying foundational principles, the results of this study indicate that they may be insufficient for developing the applied competencies and critical thinking skills required in professional transfusion practice (Abidi et al., 2025; Alharbi, 2024).

The implementation of TAPBL, however, does come with practical considerations. It requires careful instructional design, technological infrastructure, and active facilitation by faculty. Educators must invest time in crafting realistic scenarios, curating appropriate digital tools, and guiding students through collaborative problem-solving processes (Kldiashvili et al., 2025). Furthermore, institutions must ensure that students have equitable access to the necessary technology and support systems. For some students, especially those with limited digital experience, additional orientation and scaffolding may be necessary to fully benefit from the model. Faculty development is also essential; instructors must be equipped not only to deliver content but to facilitate inquiry-based, student-centered learning in digitally mediated environments (Filetti & Saso, 2020; Yulisma et al., 2023).

Despite these challenges, the long-term educational benefits of TAPBL are evident. Students emerge not only with improved test scores but with a more integrated, applied, and enduring understanding of the subject matter. They are better equipped to operate in clinical environments, more comfortable with collaborative decision-making, and more adept at using digital tools to manage complex systems. In the context of blood banking, where accurate decisions, rapid response, and effective coordination are crucial, these attributes are indispensable (Najafi et al., 2017).

Moreover, TAPBL holds promise for scalability and adaptability across diverse institutional settings. Because the model relies on flexible digital tools and modular project structures, it can be tailored to different resource levels, curricular goals, and regional healthcare priorities. It is particularly well-suited to environments where access to physical laboratories or clinical placements is limited, offering a meaningful alternative to in-person experiential learning without sacrificing realism or rigor (Hujjatusnaini et al., 2022; Pranjol et al., 2024). Perhaps the most profound insight to emerge from this study is the realization of students' latent potential when placed in the right learning conditions. Given the opportunity to engage with challenging, authentic, and collaborative tasks supported by technology and guided reflection, students consistently rose to the occasion. They demonstrated not only academic competence, but also creativity, resilience, and a desire to contribute meaningfully to future professional contexts. TAPBL provided the framework in which these capacities could emerge and flourish (Cabero-Almenara et al., 2023).

Ultimately, the significance of this study extends beyond comparative assessment scores. It offers a vision of what health sciences education can and arguably should look like in the 21st century: purposeful, participatory, and practice oriented. It calls for an evolution of educational models in step with the increasing complexity of healthcare systems, especially within fields such as transfusion medicine and laboratory science, where operational competence and technological agility are as critical as theoretical knowledge (Hujjatusnaini et al., 2022; Lee et al., 2024). In conclusion, this study demonstrates that a well-structured TAPBL model can substantially enhance both the academic achievement and professional preparedness of students in blood inventory management education. It bridges the divide between knowledge and application, between classroom instruction and clinical relevance, and between learning as memorization and learning as transformation. The voices and experiences of the students themselves affirm this: when education is grounded in purpose, supported by meaningful technology, and delivered through collaboration and reflection, it does more than impart knowledge; it shapes capable, thoughtful, and future-ready professionals.

5. CONCLUSION

This study demonstrates that the implementation of a Technology-Assisted Project-Based Learning model can significantly enhance both cognitive and affective learning outcomes of students in Blood Bank Technology programs. Through the integration of practical projects, digital tools, and collaborative learning environments, TAPBL has proven to be an effective approach for teaching complex inventory management principles that are essential to safe and efficient transfusion practices. Students exposed to TAPBL exhibited stronger conceptual understanding, higher engagement, and improved teamwork and decision-making skills compared to those taught through traditional lectures. These outcomes underline the importance of pedagogical innovation in preparing students for the realities of modern healthcare systems. The TAPBL model offers a practical, scalable solution to modernize blood bank education and bridge the gap between theory and practice in health sciences. Despite the positive outcomes, this study is limited by its one-group pre-test-post-test design without a separate control group. Future research should involve larger, multi-center samples and a controlled experimental design to further validate the

long-term impact of TAPBL on professional blood bank management.

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