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Enhancing Active Learning and Critical Thinking in Medicinal Chemistry Through Team-Based Learning

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Abstract: Team-Based Learning (TBL) is an innovative teaching method that is increasingly applied in pharmacy education to enhance engagement, collaboration, and understanding of complex subjects, such as Medicinal Chemistry. This study aimed to investigate pharmacy students' perceptions of TBL, focusing on its advantages, disadvantages, and broader implications for learning. A questionnaire structured with closed-ended and open-ended questions was used. Quantitative data were analysed using descriptive and inferential statistics, while qualitative responses underwent thematic analysis. The results indicate that students have more positive perceptions of TBL, emphasising its interactive and collaborative nature. Results reported in studies suggest TBL is effective at improving understanding of complex concepts, promoting critical thinking, and developing teamwork skills. Overall, the face-to-face TBL sessions demonstrated superior engagement and comprehension compared to their virtual counterparts, likely due to the direct exchanges. However, students reported several obstacles, including content that was too complex, having insufficient time to prepare, and difficulty with technical terminology. Despite this, group discussions, quizzes, and the practical usefulness of the material stood out as significant triggers that encourage active participation (though not obligatory). The potential of TBL to significantly enhance learning outcomes and professional skill development in pharmacy education is emphasised in this study. This study identifies substantial barriers, including preparation challenges and issues with online implementation, which can further inform the optimal use of its potential. These findings contribute to the development of TBL approaches in health-related disciplines and the context of interprofessional education.

Keywords: Collaborative problem-solving, critical thinking skills, educational barriers, student engagement, innovative learning methods.

Introduction

Active student engagement and dynamic learning environments led to innovative teaching methodologies. These approaches vary, but all combine technology, collaborative strategies, and active 3D learning models that cater to diverse learning needs while promoting critical thinking and problem-solving skills. Of all these methods, however, one has emerged as the gold standard: team-based learning (TBL), which is particularly effective in complex and interdisciplinary domains, such as medicinal chemistry. TBL's organised and interactive structure ensures student participation, accountability, and collaboration, which mitigates the drawbacks of traditional passive learning strategies and leads to higher achievement gains.

As an area of science which is inherently classified as applied, medicinal chemistry education research presents unique challenges stemming from the interdisciplinary nature of the field, which is founded on principles from chemistry, biology, and pharmacology. Students of anthropology, pharmacy, biology, and synthetic organic chemistry find themselves immediately immersed in complex molecular concepts and drug discovery and development processes (Guchhait, 2024). Due to the rapid advancement of cutting-edge technologies and the concurrent increase in disease complexity, the pharmaceutical industry will require future professional education programs that integrate technologies such as AI/ML-based drug design, nanotechnology, and microfluidics (Andrade et al., 2018; Guchhait, 2024). TBL can serve as an excellent remedy to this theory-practice gap by encouraging activated learning and deeper understanding.

There is significant literature supporting the use of TBL in medicinal chemistry education. This technique promotes early preparation and real-time group problem-solving, providing instant feedback and fostering critical thinking, long-term information retention, and collaborative practice (Dele et al., 2016; Parmelee, 2022). Research demonstrates that TBL students outperform otherwise matched students in traditional tutorial groups (Mokkapati, 2021). Moreover, TBL works exceptionally well in health professions education, demonstrating improvements in cognitive outcomes and engagement among cohorts of first-year students, academically weaker students, and nursing students (Alizadeh et al., 2024). The integration of TBL into pharmacy curricula has also been shown to enhance students' understanding of pharmacotherapy and their ability to apply basic and clinical sciences effectively (Kolluru et al., 2012).

On a global scale, TBL's implementation is a response to larger-scale educational and professional issues. In medicinal chemistry, for instance, TBL facilitates an environment in which students can collaboratively explore and apply advanced principles, such as drug solubility, stability, and metabolism, thereby achieving higher levels of Bloom's taxonomy cognitive skills (Walters, 2013). It also equips students to be at the forefront in meeting the demands of the healthcare industry, where problem-solving and teamwork, as well as independent and critical thinking abilities, are increasingly required of professionals (Minz & Saluja, 2023). Lastly, the implementation of novel concepts into curricula increases student engagement and interest in future careers in medicinal chemistry, which is in response to the worldwide decline in the workforce within this vital area (Mullin, 2003).

Overall, TBL is a practical pedagogical approach to meet the interdisciplinary challenges of medicinal chemistry education. Rather than traditional methods of lecturing, TBL encourages active learning, ICT use, and collaboration, which not only increases academic results but also equips students with the skills necessary to meet the challenges of global health and advancements in drug discovery and development (Nussbaumer, 2015). By encouraging teamwork and collaborative learning, TBL has emerged as a flexible and reliable framework to help prepare future healthcare providers with the skills and knowledge necessary to succeed in their respective fields as they develop.

Research Problem

Exploring pharmacy students' perceptions of team-based learning (TBL) in medicinal chemistry is a critical step to addressing the challenges of teaching this multidisciplinary subject. Given the fast-paced evolution of the pharmaceutical industry and the increasing complexity of concepts from medicinal chemistry, novel teaching methods such as TBL are evermore required to encourage active learning, critical thinking and group work. On the other hand, gaining insight into students' perceptions regarding this method is critical to assess its efficacy, detect potential impediments, and improve its application. This level of research is particularly timely as institutions strive to transition into more student-centric organisations to meet the demands of academia and the broader healthcare sector.

Our work advances educational practices in medicinal chemistry by examining students' experiences and attitudes toward Team-Based Learning (TBL). Filling gaps in the literature, the research highlights learners' perspectives, enabling the provision of practical recommendations to catalyse success and improve TBL optimisation. The results also have broader significance for enhancing the quality of pharmacy education, resulting in graduates with improved problem-solving and teamwork skills, which are essential for addressing global health challenges. Additionally, this work advances the academic dialogue surrounding pedagogical advancement and promotes the continued use of TBL as a relevant and beneficial approach to modern education.

Research Focus

To investigate pharmacy students' perceptions of team-based learning (TBL) is primarily carried out in the context of medicinal chemistry courses. Our research examines students' perceptions of TBL, specifically whether this pedagogical approach fosters active engagement, collaboration, and an understanding of complex interdisciplinary topics. Through exploring student attitudes, challenges, and preferences, the study aims to understand the factors that affect the effectiveness of TBL on academic outcomes and student engagement.

The study is underpinned by the recognition that practitioners must understand students' perspectives to facilitate optimal TBL implementation. The authors aim to extract information on learners' perspectives of TBL strengths and limitations to offer recommendations for evidence-informed and focused modifications. Moreover, the study aims to contribute to the broader debate on innovative pedagogical approaches in pharmacy education, with a particular emphasis on TBL as a crucial component in equipping students with the complexities of contemporary pharmaceutical practice.

Research Aim and Research Questions

The purpose of this study was to investigate pharmacy students' perceptions of team-based learning (TBL) in medicinal chemistry courses, evaluating its effectiveness as a pedagogical approach. It aims to examine the impact of TBL on students' engagement, teamwork, and understanding of complex topics in medicinal chemistry. In doing so, the study endeavours to present the practical implications of improving the utilisation of TBL in pharmaceutical education and validating its relevance in shaping the evolving expectations for the healthcare and industrial sectors.

In doing so, this study is guided by the following research questions:

1. What are pharmacy students' overall perceptions of team-based learning in medicinal chemistry courses?
2. What are the effects of TBL on student engagement and motivation in the field of medicinal chemistry?
3. What challenges do students encounter in implementing TBL in medicinal chemistry courses?
4. In what ways does TBL promote students' mastery of medicinal chemistry concepts?
5. What changes, if any, could be implemented to improve the precision of TBL in medicinal chemistry teaching?

These research questions reflect the principal issues raised by the study above and aim to deliver a thorough overview of the TBL´s significance in medicinal chemistry. The results intend to enhance the development of advanced teaching methodologies within pharmacy programs.

Literature Review

Theoretical Foundation

Team-Based Learning (TBL) is grounded in various educational theories, with constructivist learning theory being one of its primary theoretical foundations. This theory emphasises that learners are not passive recipients of information but rather active agents building knowledge through profound experiences and interactions (Hrynchak & Batty, 2012). This article describes how TBL can be adapted to foster learning in active learning environments that have traditionally been passive, engaging students in problem-solving and critical thinking, which are key goals of health professions and science education (Michaelsen et al., 2008). This episode offers a glimpse into how a student-centred approach to team-based learning (TBL), which has the potential to tackle the complex and extensive curriculum of medicinal chemistry, can spark student-led, excitement-driven learning within such a sprawling and complicated subject (Li et al., 2022).

The structured approach of TBL—in which students prepare before class, apply their knowledge during class, and then reflect on it afterwards—fosters an environment for effective learning rich in feedback (Levine & Hudes, 2021). Central to this approach is the readiness assurance process, which ensures that students are at least prepared to engage in higher-order thinking and application tasks (Levine & Hudes, 2021). Furthermore, TBL promotes responsibility through individual and group accountability, a crucial skill in healthcare professions (Johnson, 2009). These simulations have the potential to develop fundamental skills such as teamwork and critical thinking, which are of utmost importance in healthcare education, by allowing real-time decision-making and instant feedback (Burgess & Matar, 2023). Moreover, TBL has proven effective in keeping large groups engaged through expert-facilitated, interactive sessions that promote peer teaching and analytical problem-solving (Parmelee, 2022; Parmelee & Al-Kadi, 2014).

TBL's theoretical foundations and systematic approach make it an invaluable teaching tool in medicinal chemistry and other healthcare-related subjects. Applying new knowledge to gained knowledge along this collaborative, process-oriented continuum is how team-based methods of instruction promote critical thinking and professional preparation (Parmelee et al., 2012; Thomas & Sabina, 2021).

Global Trends in TBL Implementation

Team-Based Learning (TBL) has been widely adopted in pharmacy and medicinal chemistry education worldwide, marking a precursor to an active shift towards active learning in senior education. Team-based learning (TBL) is frequently utilised in pharmacy programs across the United States, with a focus on small team dynamics, readiness assurance, and immediate feedback to increase student engagement and improve learning outcomes (Farland et al., 2013). The differences in student performance, although statistically insignificant (suggesting the need for further examination to understand the impact of TBL on pharmacy education fully), were generally higher among students receiving TBL compared with those receiving traditional teaching methodologies (Korayem et al., 2024).

Pharmaceutical care courses in Japan integrated TBL as well and found that it was effective for active learning, with student satisfaction improving through TBL. The Report Card also found better performance in group assessments than in individual assessments (Suno et al., 2013). In China, TBL has been employed for similar purposes, with the additional benefit of promoting theoretical knowledge and fostering essential skills, such as communication and self-directed learning, thereby bridging the alignment between the country's educational needs and TBL (Lang et al., 2019). In South Africa, TBL has also been beneficial in fostering critical generic skills that are necessary in the workplace for a career in pharmacy)Some of these include teamwork, problem-solving, and public speaking (Eksteen, 2019).

By enhancing communication, emotional intelligence, and accountability—qualities essential for being effective in healthcare environments—TBL could also promote the development of leadership skills in pharmacy learners (Haight & Brooks, 2022). These factors include juggling the coordinated schedules of workshops and ensuring relevant discussions take place; however, the international adoption of TBL is evidence of its flexibility and success in many educational settings (Tweddell, 2020). These examples demonstrate the increasing uptake of TBL as a pedagogical method within pharmacy and medicinal chemistry courses internationally, which is at least in part motivated by its potential to enhance learning outcomes and develop key skills for professional practice.

Benefits and Challenges of TBL

Team-Based Learning fosters heightened engagement among students and has proven highly valuable in tertiary education, particularly for advanced topics such as medicinal chemistry. Team-Based Learning (TBL) is an educational strategy designed to intentionally cultivate the knowledge, skills, and attitudes vital to any profession: active learning, critical thinking, and teamwork, enabling individuals to thrive in complex situations and real-world problems (Burgess & Matar, 2023; Minz & Saluja, 2023). However, in areas such as medicinal chemistry, where content is complex and widely disseminated, TBL has been shown to enhance student engagement and proactivity, ultimately increasing the effectiveness of learning (Li et al., 2022).

Through its structured format, which includes pre-class individual work, in-class group work, and post-class review, TBL prompts students to activate their knowledge and apply it to authentic, real-world applications (Li et al., 2022; Walters, 2013). Not only does this method support information retention, but it also improves problem-solving and teamwork abilities (Hur et al., 2013; Leupen, 2020). Nonetheless, the successful implementation of TBL takes careful planning and facilitation to ensure that all students are both prepared and engaged (Burgess & Matar, 2023; Thomas & Sabina, 2021). Moreover, the success of TBL will depend on the complexity and relevance of the problems posed (Leupen, 2020).

Nonetheless, TBL's focus on immediate feedback and peer accountability contributes to a motivating learning climate in which students take responsibility for individual work as well as that of their peers (Finn, 2015; Thomas & Sabina, 2021). Though this method requires a considerable amount of time and work to construct and implement, the results, such as greater engagement, more students collaborating, and more substantial learning outcomes, make TBL an incredible asset for higher education, especially when teaching complex subjects such as medicinal chemistry (Li et al., 2022; Minz & Saluja, 2023; Walters, 2013).

Conflicts in Theory and Practice

Research on Team-Based Learning (TBL) yields heterogeneous results that are sometimes contradictory, and the literature can be divided into three categories based on how they approach these discrepancies. Haidet et al. (2014) extol the benefits of TBL, including enhanced knowledge gain and team performance, yet urge more thorough research and precise reporting to account for conflicting findings. Similarly, Zhan et al. (2019) suggest that while TBL has been widely adopted in university teaching, many unanswered questions related to its use remain that warrant further exploration if TBL is to develop sensibly.

Conversely, Boers and Faez (2023) argue that many meta-analytic reviews of task-based programs may not fulfil their intended functions, thereby complicating the understanding of the effectiveness of TBL (Boers & Faez, 2023). We note that Hacke and Nunan (2019) have similarly observed that inconsistent methods of review are a significant cause of conflicting findings due to methodological differences in reviews and the extraction of data. On the other hand, Yunikawati and Tuanani's (2022) comparative study, which examined the effectiveness of TBL and Problem-Based Learning (PBL) in economics education, concluded that TBL is more effective than PBL in fostering critical thinking but highlighted the need for further research on TBL's impact on other skills. Miracle (2004) further emphasises that understanding the processes behind research can provide a better perspective on findings, allowing them to be adapted to the context in the face of conflicting investigation results.

These studies suggest that although TBL is generally viewed as advantageous, discrepancies often arise from methodological differences, variations in definitions of TBL components, and difficulties in precise execution and reporting. Standardisation of methodologies, more explicit definitions, and improved research practices can help resolve discrepancies in TBL's effectiveness and promote a common understanding.

Research Gaps

Team-Based Learning (TBL) has been widely adopted in pharmacy and medicinal chemistry education globally, reflecting a worldwide trend toward active learning strategies in higher education. TBL is widely used in pharmacy programs in the United States with its emphasis on teamwork, revised assurance of learning, and immediate feedback as a means of engaging students and improving learning outcomes (Farland et al., 2013). In pharmacy education, a meta-analysis comparing TBL to conventional teaching methods found that TBL significantly enhanced student performance; however, the differences were not statistically significant, indicating a need for further research to fully understand its efficacy (Korayem et al., 2024).

In Japan, TBL has been integrated into pharmaceutical care education, which not only enhances active learning engagement but also improves student satisfaction, as group assessment performance is reported to be higher than that of individual assessments (Suno et al., 2013). Similarly, In China, TBL has also been successfully adopted to improve theoretical knowledge as well as critical skills such as communication and self-directed learning, which further demonstrates the alignment of TBL with the educational framework (Lang et al., 2019). In South Africa, TBL has also been shown to be effective in cultivating critical generic skills, such as teamwork and problem-solving skills, all of which are key aspects of employability in the pharmacy profession (Eksteen, 2019).

In addition, TBL has been proven to further develop leadership skills in pharmacy students, enhancing communication skills, emotional intelligence, and accountability —essential skills in healthcare systems (Haight & Brooks, 2022). TBL has faced criticism, but its widespread adoption across the globe captivates in leading a quality way in learning gain and skill development. These examples demonstrate the versatility of TBL and its growing relevance in pharmacy and medicinal chemistry education worldwide, thereby expanding its utility as an educational framework for diverse learning contexts (Tweddell, 2020).

Relevance to Local and Global Contexts

Team-Based Learning (TBL) can be highly relevant or entirely irrelevant in many educational contexts, whether local or global. In part, the success or failure of TBL depends on the social and institutional context in which it occurs. While TBL has been shown to demonstrate a clear and significant improvement in student motivation and teamwork skills, including within medical education as a whole, such findings appear limited to localised contexts; for example, a University of Rio de Janeiro study examined both comprehension that goes further than simple rote memorisation, with students experiencing TBL to cover material on the digestive system (Costa & Corrêa, 2024). This was also the case in some universities in Sudan, such as Alfajr College, where TBL was positively perceived by students (Elameen, 2023).

Globally, Team-Based Learning (TBL) is a popular innovation applied in health professions education, with a wealth of research evidence emerging from countries such as the United States and China, showing its success in enhancing cognitive and clinical performance outcomes (Alizadeh et al., 2024). Yet, TBL has a culturally determined context that causes variability in its effectiveness in fostering student engagement and predisposition towards collaborative learning (Silva et al., 2022). For example, a study in China found that female students and those less academically prepared learn better through TBL, highlighting cultural differences in learning preferences (Alizadeh et al., 2024). Moreover, the role of an institution in TBL is significant and as important as the faculty training and resources needed for TBL (Burgess & Matar, 2023).

Responses to the transition to online TBL have varied. Others report similar levels of acceptance for traditional face-to-face sessions but face challenges such as student overload and a limited understanding of TBL benefits (Silva et al., 2022). The design of the method, with attention to preparation before class, collaborative parties that include feedback, and just-in-time learning, continues to be essential aspects for building accountability and active learning, ensuring that TBL remains a versatile tool relevant across the apparent boundaries of disciplines and educational contexts (Burgess & Matar, 2023). In conclusion, each of the principles of TBL can be effectively applied regardless of where students are located in the world; however, no one-size-fits-all solution exists, and such an approach will necessitate cultural and institutional considerations to maximise the educational potential of TBL.

Empirical Evidence and Data Interpretation

Empirical studies provide strong evidence to suggest that Team-Based Learning (TBL) is a powerful tool for enhancing learning outcomes, engagement, and understanding of complex topics, particularly in medicinal chemistry and related areas. TBL is of interest and motivation to students in courses on medicinal chemistry, which is a challenging and broad subject (Li et al., 2022). The approach has yielded higher exam scores, as well as increased professionalism, engagement, and peer learning in pharmacokinetics; however, it also increases faculty workload (Methaneethorn & Methaneethorn, 2022).

Notably, in the context of biomedical engineering, TBL has been associated with high short- and long-term retention of content (Haase et al., 2017), as well as improvements in performance on team-based assessments compared to individual-based assessments. TBL promotes higher-order thinking in students engaged in medicinal chemistry, as students need to analyse and apply concepts rather than memorise them (Walters, 2013). A recent umbrella review examining TBL in health professions education suggests strong evidence for its ability to enhance cognitive outcomes and engagement; however, the impact of TBL on retention remains uncertain (Alizadeh et al., 2024). Significantly more significant academic gains were detected by follow-up assessments post-TBL in students undergoing anatomy training using the TBL mode of education (Dnyanesh et al., 2024). In community medicine, for instance, TBL has received favourable reviews from students and faculty, along with substantial improvements in test scores (Thirunaaukarasu et al., 2024).

Research also indicates that, although the stability of teams in TBL does not have a statistically significant influence on cognitive outcomes, the collaborative nature of the method consistently improves learning (Heber et al., 2024). In the field of pharmacy education, a meta-analysis has also demonstrated that TBL is superior to traditional methods of teaching in terms of student performance; however, the differences were not statistically significant (Korayem et al., 2024). For example, TBL was applied among pharmacists in online environments, and it proved promising, as it improved readiness assurance test scores (Aimiya et al., 2024). Taken together, these results highlight the value of TBL in providing opportunities for collaboration, enhancing learner outcomes, and engaging students in traditionally challenging disciplines, such as medicinal chemistry.

Materials and Methods

Sample and Participants

The subjects of this study were undergraduate students in the Applied Pharmacy program at Poltekkes Kemenkes Makassar, located in Makassar, the Capital City of South Sulawesi Province, Indonesia. A purposive sampling technique was used to focus on students who had prior exposure to Team-Based Learning (TBL) in the context of their Medicinal Chemistry curriculum. Typically, purposive sampling was adopted to ensure that only students with direct exposure to TBL were included, thereby guaranteeing the directness and relevance of their insights and perceptions to the research. In addition, to assist the selection process, a criterion-based sampling strategy was utilised, in which the inclusion criteria consisted of students who had actively participated in TBL activities during their classes. A total of 98 students from the 2019 and 2020 cohorts participated. Sampling occurred in two steps to ensure that the research participants were individuals with direct experience of TBL, thereby increasing the validity of the findings.

Instrument and Procedure

We employed a structured questionnaire as the data collection instrument, comprising both closed-ended and open-ended questions. The questionnaire was derived from validated instruments used in other research studies to assess students' perceptions of TBL and adapted to align with the research goals and the local educational context. The questionnaire was pretested with 20 students and expert-validated for clarity, reliability, and relevance.

The questionnaire focused on four domains:

1. Basic Concepts of Medicinal Chemistry: Familiarity with fundamental principles.
2. Implementation of TBL Experiences with TBL.
3. Phases of TBL: Pre-class preparation, in-class teamwork and post-class feedback
4. Impact of TBL: Perceived benefits, challenges and overall satisfaction with TBL.

The final version of the questionnaire included closed-answer questions with response options rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree), as well as open-answer questions to gather qualitative insights. Surveys were administered online through a Secure survey platform over two weeks, with periodic reminders to maximise participation.

Data Analysis

Quantitative Data:

Closed-ended responses were analysed using descriptive statistics (i.e., means, standard deviations, and frequencies) to identify trends in the data. The perceptions of the 2019 and 2020 cohorts were compared using inferential statistics and independent samples t-tests. SPSS version 29 was used for the statistical data processing. Before running the t-tests, we checked for assumptions for normality and homogeneity of variances. These analyses provided insights into overall impressions and differences between groups.

Qualitative Data:

Open-ended responses were analysed using thematic analysis, a systematic method employed to find and interpret patterns or themes in the data. The process of thematic analysis involved the following steps:

1. *Familiarization*: Reading through all responses multiple times to acquire a holistic understanding of the data.
2. *Coding*: Identifying key pieces of text and applying codes that accurately reflect the central ideas or concepts.
3. *Theme Identification*: Identifying broader themes by grouping similar codes that reflect significant patterns in the data.
4. *Reviewing and Refining Themes*: Making sure that themes are separate and logically sound, ensuring they correspond to the aims of the research
5. *Reporting*: Writing a detailed place-based description of the themes, supplemented by quotes — often illustrative — from participants to shed light on their understandings.

This mixed-methods approach, employing both thematic analysis and quantitative techniques, enabled a comprehensive understanding of students' perceptions of TBL and its effectiveness in Medicinal Chemistry education.

Results

Instrument Validity and Reliability

The validity and reliability of the questionnaire used in this study were assessed and presented, ensuring the use of a robust data collection instrument. The validity test confirmed that all questionnaire items were valid about the measured constructs (Table 1).

Table 1

Validity Analysis

Item of Question	R-value (Pearson Correlation)	Criteria
Q1	0.620	Valid
Q2	0.538	Valid
Q3	0.559	Valid
Q4	0.507	Valid
Q5	0.329	Valid
Q6	0.674	Valid
Q7	0.433	Valid
Q8	0.424	Valid
Q9	0.587	Valid
Q10	0.805	Valid
Q11	0.717	Valid
Q12	0.635	Valid
Q13	0.730	Valid
Q14	0.511	Valid
Q15	0.644	Valid
Q16	0.698	Valid
Q17	0.560	Valid
Q18	0.655	Valid
Q19	0.665	Valid
Q20	0.771	Valid
Q21	0.787	Valid
Q22	0.620	Valid
Q23	0.744	Valid
Q24	0.657	Valid
Q25	0.611	Valid

The internal consistency of all items was excellent, as indicated by a reliability coefficient of Cronbach's Alpha = 0.925 (Table 2). This finding indicates that the Questionnaire was a valid instrument for measuring the TBL perspectives of medicinal chemistry students and professionals.

Table 2

Reliability Statistics

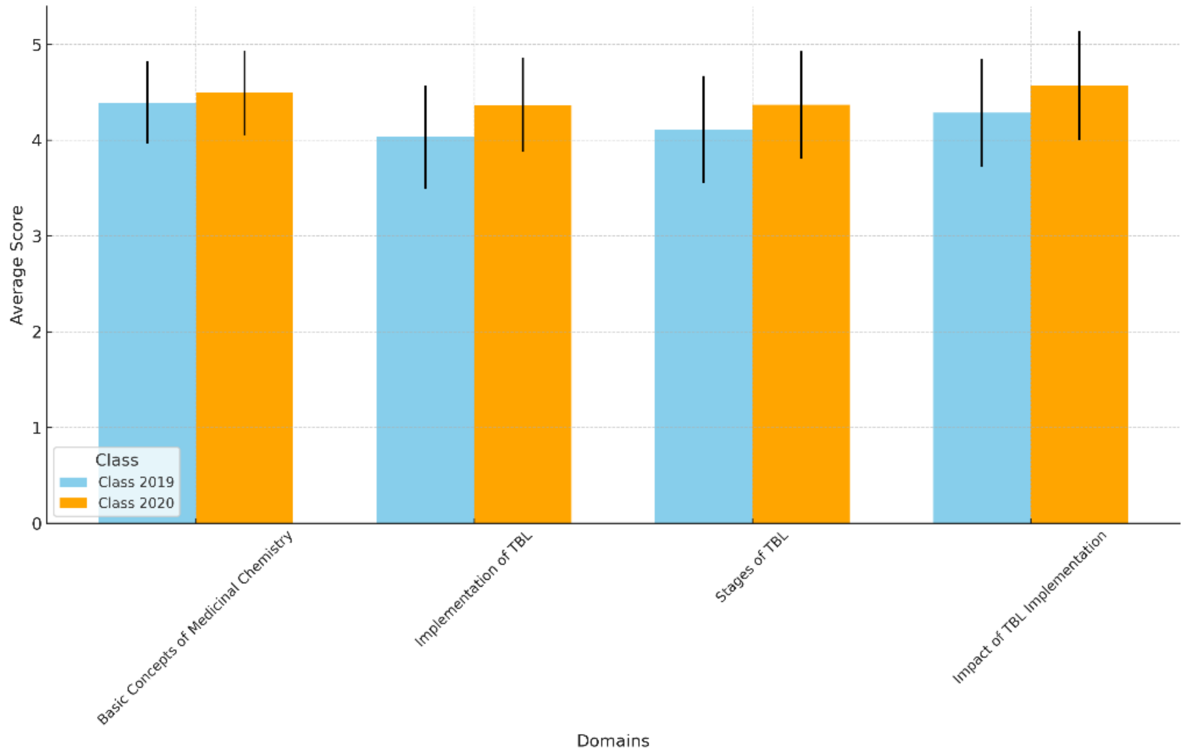
Cronbach's Alpha	N of items
0.925	25

Quantitative Analysis

The quantitative analysis of closed-ended responses revealed the following key findings across the four domains assessed (Figure 1).

Figure 1

Comparison of Average Scores Across Domains Between Classes



Quantitative findings showed positive perceptions of TBL across both the 2019 and 2020 cohorts, with some notable differences. For the **basic concepts of Medicinal Chemistry**, students from the 2020 cohort who experienced TBL in a face-to-face setting reported a slightly higher mean score of 4.4 compared to 4.0 in the 2019 cohort who participated in TBL online. This suggests that the in-person format may have contributed to a better understanding of complex material. Similarly, engagement levels in the **implementation of the TBL** domain were higher for the 2020 cohort (mean: 4.6) than the 2019 cohort (mean: 4.3), likely due to the increased opportunities for direct interaction in the classroom setting.

In the **phases of TBL**, both cohorts reported positive experiences with in-class teamwork, with mean scores of 4.6 for the 2019 cohort and 4.7 for the 2020 cohort. However, the 2019 cohort rated pre-class preparation lower (mean: 3.8) compared to the 2020 cohort (mean: 4.0), indicating that students may have faced additional challenges preparing for online sessions. Immediate feedback during sessions was similarly valued by both cohorts, with high levels of appreciation reported (2019: 81%, 2020: 83%).

In the **impact of TBL**, students from both cohorts highlighted improvements in critical thinking and teamwork skills, although the 2020 cohort rated these domains slightly higher (critical thinking mean: 4.5; teamwork mean: 4.6) compared to the 2019 cohort (critical thinking mean: 4.2; teamwork mean: 4.3). Additionally, the relevance of TBL to real-world pharmaceutical applications was frequently mentioned, with 90% of the 2020 cohort agreeing that TBL connected theory to practice, compared to 86% in the 2019 cohort.

Qualitative Analysis

Thematic analysis of open-ended responses provided more profound insights into students' perceptions of TBL (Table 3). Three primary themes emerged:

Table 3

Qualitative Analysis

Themes	Finding	Example
Positive Perception of TBL	• Engagement and Active Participation: Students reported that TBL was highly engaging, primarily through activities such as group discussions, collaborative problem-solving exercises, and quizzes. • Deeper Understanding: TBL helped students grasp complex Medicinal Chemistry concepts more effectively compared to traditional methods. • Teamwork: Students appreciated the collaborative environment fostered by TBL, which enhanced their learning experience.	• *"Group discussions make learning fun and effective for understanding complex topics."* • *"TBL helps us work together and learn from each other."*
Barriers to Learning	• Complexity of Material: Medicinal Chemistry concepts, such as calculations, chemical structures, and drug interactions, were perceived as challenging. • Limited Preparation Time: Students expressed frustration over the limited time to prepare for discussions and quizzes. • Language Barriers: The technical language used in modules and quizzes made it difficult for some students to comprehend the material. • Online Learning Challenges: During the pandemic, online learning introduced difficulties such as network issues and reduced direct interaction.	• *"The material is difficult to understand, particularly in terms of chemical structures and drug interactions."* • *"The time allocated for preparing for quizzes is too short."*
Motivations for Learning	• Group Discussions: Collaborative discussions were seen as a key motivator for engaging with the material and understanding complex topics. • Quizzes and Challenges: The inclusion of quizzes and case-based problem-solving activities inspired students to learn more deeply.	• *"Solving quizzes in groups motivates me to think critically."* • *"Learning about drug activities makes me excited to explore more about pharmaceuticals."*

	• Real-World Relevance: Students found the study of drug structures and their biological activities fascinating and relevant, motivating them to explore more about pharmaceuticals.	

Qualitative analysis of open-ended responses further highlighted these differences. The 2020 group also highlighted the benefits of direct peer exchanges and in-person conversations, which they claimed were more engaging and supportive of growth. Conversely, the 2019 cohort expressed concerns about network issues and decreased interaction during online TBL, which affected their overall learning experience. Group discussions, quizzes, and real-world relevance were the most motivating factors for both cohorts, while material complexity and minimal preparation time were the most pressing shared barriers.

Overall, the results suggest that both online and face-to-face TBL formats are successful in fostering engagement, collaboration, and understanding; however, the use of an in-person setting enhances these outcomes to a greater degree. Closing the gaps in online TBL TBL across learning formats

Discussion

This study offers valuable insights into pharmacy students' perceptions of Team-Based Learning (TBL) in Medicinal Chemistry, reinforcing its effectiveness as a pedagogical approach. Students highly valued the interactive nature of TBL, particularly group work and problem-solving activities, which facilitated a better understanding of complex concepts. Additionally, the study found high levels of student engagement, supporting previous research suggesting that TBL fosters motivation, teamwork skills, and critical thinking. However, specific challenges were identified, including the complexity of Medicinal Chemistry concepts, limited preparation time, and the use of technical language, which some students found difficult to navigate. The transition to online TBL during the pandemic further exacerbated these challenges, introducing issues such as network problems, reduced interaction, and decreased perceived commitment.

The favourable perception of TBL in this study aligns with previous literature, which highlights how this approach enhances student engagement, critical thinking, and teamwork abilities (Burgess & Matar, 2023; Minz & Saluja, 2023). The students' appreciation for the interactive learning experience is consistent with Walters (2013), who emphasised the role of TBL in developing higher-order cognitive skills. Moreover, the high reliability and validity of the questionnaire used in this study (Cronbach's alpha = 0.925) reinforce confidence in these findings. The levels of student engagement reported are in line with global research conducted in the US and Japan, which demonstrated that TBL enhances motivation and collaboration in pharmacy education (Farland et al., 2013; Suno et al., 2013). The benefits of peer-to-peer interaction and immediate feedback are also supported by research in health professions education, which has demonstrated the positive influence of TBL on cognitive and clinical performance (Alizadeh et al., 2024).

Despite the positive perception, students reported challenges with TBL, particularly regarding the complexity of the subject matter and limited preparation time. This finding aligns with Silva et al. (2021), who emphasised that successful TBL implementation depends on contextual factors, such as access to preparatory materials and sufficient pre-class preparation time. The difficulties associated with online TBL are also consistent with Tweddell's (2020) findings, which noted that virtual TBL introduced technical issues and reduced student engagement. From a motivation perspective, quizzes and real-world applications emerged as major drivers of student engagement, reinforcing the findings by Li et al.

(2022), who stated that problem-solving activities linking theoretical knowledge to real-world contexts enhance learning motivation. Specifically, students found the real-world relevance of Medicinal Chemistry concepts, drug structures, and activities highly engaging, a finding that aligns with Methaneethorn and Methaneethorn (2022), who reported similar effects in pharmacokinetics education.

These findings have several theoretical and practical implications for the field of pharmacy education. First, optimising TBL implementation by enhancing preparatory materials, providing sufficient pre-class time, and simplifying technical language can improve student learning outcomes. Second, given the flexibility of TBL in both online and in-person settings, institutions can explore blended learning approaches to maximise its benefits while minimising engagement barriers. Third, the global adaptability of TBL has been widely recognised in various educational settings, including Japan and China (Lang et al., 2019; Suno et al., 2013), but contextual differences may lead to variations in student experiences, reinforcing the need for standardised TBL practices (Hacke & Nunan, 2019). Finally, integrating real-world applications into TBL activities may help bridge the gap between theoretical knowledge and practical skills, thereby better preparing students for their future roles as pharmacists.

Despite its contributions, this study has several limitations. First, the focus on a specific cohort of pharmacy students may limit the generalizability of the findings to other educational settings or disciplines. Second, the reliance on self-reported data introduces the possibility of response bias, as students may have over- or under-reported their experiences. Third, the study provides only a snapshot of student perceptions at a single point in time, and future research should explore the long-term impacts of TBL on student performance and knowledge retention. Additionally, the transition to online learning during the pandemic may have influenced students' perceptions, making it difficult to fully isolate the effectiveness of TBL from the challenges of remote learning.

To address these limitations, future studies should investigate the impact of customised interventions, such as increased preparation time or digital enhancements, on improving TBL in both online and in-person formats. Cross-cultural comparisons of TBL implementation could provide valuable insights into how different educational contexts influence student experiences and learning outcomes. Furthermore, longitudinal studies tracking the long-term effectiveness of TBL on knowledge retention and clinical competency in pharmacy students could offer a deeper understanding of its impact.

In conclusion, this study reinforces the effectiveness of the TBL instructional strategy in pharmacy education. While students generally perceive TBL positively, the challenges identified highlight areas for improvement in its implementation and delivery. By addressing these barriers, educators can enhance student engagement and learning outcomes, ultimately better preparing future pharmacists to meet the evolving challenges of modern healthcare.

Conclusions

This study is the first to provide an in-depth understanding of pharmacy students' experiences during TBL in Medicinal Chemistry, emphasising both the strengths and weaknesses of TBL implementation in this context. The results demonstrate that TBL is a practical pedagogical approach that fosters collaboration, engagement, and a deeper consideration of complex topics. Students responded positively to TBL, explicitly enjoying the interactive nature of the class, the cooperative problem-solving environment, and the practical applications for real-world data. Furthermore, the face-to-face versatility of TBL was found to amplify these advantages compared to the online format, highlighting how personal contact can increase the implementation effectiveness of TBL methodology.

However, there were significant barriers, including the complexity of Medicinal Chemistry material, time constraints, and difficulties with technical language, particularly in the online format. These results suggest the need for improved preparatory materials, longer pre-curricular preparation periods, and more explicit language to promote better understanding and participation. Overcoming these challenges can help TBL thrive in diverse learning environments.

The study further highlights the opportunity for TBL to develop business skills in students, making them more prepared for the workforce in the pharmaceutical profession, including areas such as critical thinking, teamwork, and problem-solving. Whilst this research affirms the value of TBL, there is a need for additional research to identify techniques that best optimise its use, particularly in online formats, and to understand the long-term impacts of TBL on student learning and their inherent work performance. Investigating these frameworks cross-culturally can provide insight into how to tailor TBL to the needs of different populations of students and educational environments.

In summary, TBL is an engaging and flexible method for teaching Medicinal Chemistry. Through its continued evolution, including addressing established weaknesses and building upon its inherent strengths, the framework can genuinely have a significant impact, setting students up for success within the complexity of their future pharmacy and healthcare careers.

Suggestions for future research

Future studies should aim to overcome the barriers presented in this survey, including the complexities associated with medicinal chemistry materials, negative comments regarding the time allocated for preparation, and difficulties with specialised vocabulary. Possible approaches, for example, enhancing the transparency and availability of preparation materials and allowing more time for pre-class preparation, should also be pursued to enhance TBL implementation. Further studies may also explore the incorporation of digital tools, gamification and improved online platforms to fine-tune TBL at virtual learning environments. This improvement could help alleviate the shortcomings observed in the online version of TBL.

Moreover, there is a need for longer-term studies to assess how TBL affects students' academic and career outcomes, especially concerning fostering critical thinking. These teamwork and problem-solving skills are integral to the pharmaceutical profession. Indeed, cross-cultural and comparative research may shed light on how TBL can be adapted to best fit local educational contexts and aspects, thereby enhancing its global appropriateness and applicability. If successful, extending TBL to additional multidisciplinary areas of healthcare, such as biotechnology, or in another scientific career pathway, i.e., clinical pharmacy, would lend more evidence to its efficacy as a versatile teaching approach in the health sciences.

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Conflict of Interest

None.

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