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Exploring Students' Critical Thinking through Flipped Classroom Approach in Chemistry Learning at Penang Straits International School

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ABSTRACT

The cultivation of critical thinking skills has become a central goal of 21st-century science education, including in chemistry learning. However, studies on the flipped classroom model in international school settings, particularly in Southeast Asia, remain limited. This study aims to examine the effectiveness of the flipped classroom approach in enhancing students' critical thinking skills in chemistry at Penang Straits International School. A qualitative descriptive design with quantitative support (mixed-method emphasis) was employed, involving 28 Year 10 students over an eight-week intervention. Data were collected through classroom observations, student journals, semi-structured interviews, and pre–post critical thinking tests. The findings showed significant improvements in students' abilities to analyze, evaluate, and construct arguments, supported by higher post-test scores. Thematic analysis revealed that students became more autonomous, engaged, and confident in applying chemical concepts to problem-solving tasks. Teachers also reported a shift toward more student-centered classroom interactions. The study concludes that the flipped classroom model is an effective pedagogical strategy for fostering critical thinking in chemistry learning, though its implementation requires careful monitoring of students' pre-class preparation.

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INTRODUCTION

In the evolving landscape of 21st-century education, critical thinking has emerged as a pivotal skill, particularly in the realm of science education. Chemistry, with its intricate concepts and abstract theories, demands not only rote memorization but also analytical reasoning and problem-solving abilities. Traditional pedagogical approaches, often characterized by passive learning, have been increasingly scrutinized for their limited capacity to cultivate such higher-order thinking skills.

The flipped classroom model has garnered attention as a transformative pedagogical strategy aimed at enhancing student engagement and fostering critical thinking. By inverting the conventional teaching paradigm—delivering instructional content outside the classroom and utilizing class time for interactive activities—this approach seeks to promote active learning and deeper cognitive engagement. Recent studies have underscored the efficacy of flipped classrooms in improving student performance and problem-solving skills in secondary school chemistry courses. *pubs.rsc.org+1pubs.rsc.org+1*

Furthermore, integrating technological frameworks such as Technological Pedagogical Content Knowledge (TPACK) into flipped classroom models has shown promise in enhancing students' critical thinking and creativity. A study by Mustadi, Ghufron, and Fakhrudin (2024) demonstrated significant improvements in students' analytical and evaluative skills when exposed to a TPACK-based flipped learning environment. *Learning Gate*

The role of interactive and indirect instruction within flipped classrooms has also been explored. Borja and Panoy (2024) found that such instructional strategies effectively developed critical thinking skills among Grade 10 students in science classrooms, emphasizing the importance of student-centered learning activities. *eJournal UPSI*

In the context of chemistry education, the flipped classroom approach has been linked to enhanced understanding of chemical concepts and increased student motivation. Studies have highlighted the value of independent pre-class learning and the promotion of deeper comprehension during in-person instruction .

These findings suggest that flipped classrooms can facilitate a more profound grasp of chemical principles by encouraging students to engage with the material actively. *ACS Publications*

Moreover, the integration of artificial intelligence tools, such as ChatGPT and Bing Chat, into flipped classroom settings has been investigated for their potential to support critical thinking. Dos Santos (2023) reported that these AI agents acted as "agents-to-think-with," fostering students' problem-solving abilities and conceptual understanding in chemistry. *arXiv*

The effectiveness of flipped classrooms in enhancing critical thinking is not limited to higher education. Putro et al. (2024) demonstrated that the flipped classroom model significantly improved critical thinking skills among students in secondary education, as measured by the Cornell Critical Thinking Test . This suggests the model's applicability across various educational levels. *pubs.rsc.org+1IntechOpen+1Atlantis Press*

Additionally, the combination of case-based learning with flipped classrooms has been shown to improve active learning and critical thinking among international students. A study published in BMC Medical Education (2024) found that this hybrid approach enhanced students' engagement and analytical skills in medical education contexts . *BioMed Central*

In the realm of blended learning, the flipped classroom model has been identified as a key component in developing students' critical thinking skills. Luciana et al. (2024) conducted a meta-analysis revealing that flipped classroom-based blended learning positively influences students' critical thinking, with a high effect size. *petier.org*

The application of flipped classrooms in history education has also yielded positive outcomes. Fadli et al. (2024) reported that implementing the flipped classroom model in history learning significantly improved students' critical thinking abilities, highlighting the model's versatility across disciplines. *IJERE*

Despite the growing body of evidence supporting the flipped classroom approach, its implementation in international school settings, particularly in Southeast Asia, remains underexplored. Penang Straits International School, with its diverse student body and emphasis on holistic education, presents an ideal context for investigating the efficacy of flipped classrooms in enhancing critical thinking in chemistry learning.

This study aims to fill the gap in existing literature by examining the impact of the flipped classroom approach on students' critical thinking skills in chemistry at Penang Straits International School. By employing a qualitative descriptive methodology, the research seeks to provide nuanced insights into how flipped classrooms influence students' analytical, evaluative, and problem-solving abilities.

The findings of this study are expected to contribute to the broader discourse on innovative pedagogical strategies in science education. By elucidating the relationship between flipped classrooms and critical thinking, the research aims to inform educators, policymakers, and curriculum developers seeking to enhance educational outcomes in chemistry and other STEM subjects.

Furthermore, the study will explore the challenges and opportunities associated with implementing flipped classrooms in international school contexts. Factors such as cultural diversity, language proficiency, and technological infrastructure will be considered to provide a comprehensive understanding of the model's applicability and effectiveness.

In conclusion, as education continues to evolve in response to the demands of the 21st century, pedagogical innovations like the flipped classroom offer promising avenues for fostering critical thinking. This study endeavors to shed light on the potential of such approaches in enhancing chemistry learning at Penang Straits International School, thereby contributing to the advancement of science education in international settings.

RESEARCH METHOD

This study employed a mixed-method design with a qualitative descriptive emphasis to explore the effectiveness of the flipped classroom approach in enhancing students' critical thinking skills in chemistry. The selection of this design was motivated by the research objective, which was not only to measure the improvement in students' critical thinking skills quantitatively through pre- and post-tests, but also to gain an in-depth understanding of students' learning experiences, classroom interactions, and the evolving role of teachers in a flipped learning environment. By combining numerical evidence with rich narrative data, the study aimed to provide a more holistic and contextualized account of how the flipped classroom influences critical thinking development in an international school setting.

The research was conducted at Penang Straits International School, Malaysia, which is known for its multicultural student population and inquiry-based curriculum. The participants consisted of 28 Year 10 chemistry students who were selected through purposive sampling. This sampling method was deemed appropriate because the students had prior exposure to both conventional and digital learning, making them suitable for comparison under the flipped classroom model. Additionally, the chemistry teacher who facilitated the flipped classroom served as a key informant, providing valuable pedagogical perspectives and supporting data triangulation.

The flipped classroom intervention was implemented over a period of eight weeks. During the pre-class phase, students were required to study instructional materials consisting of recorded video lectures, assigned readings, and guiding questions uploaded onto the school's Learning Management System (LMS). These resources were intended for independent study at home and served as preparation for in-class activities. The face-to-face classroom sessions were then dedicated to active learning activities such as group problem-solving, Socratic questioning, guided discussions, and small-scale experiments on key chemistry topics including stoichiometry, atomic theory, and reaction mechanisms. The teacher's role shifted from that of a knowledge transmitter to a facilitator who guided discussions, posed critical questions, and conducted formative assessments to monitor students' understanding.

Data collection involved four key instruments. First, a critical thinking test administered pre- and post-intervention, adapted from the Cornell Critical Thinking Test, was used to measure students' analytical, evaluative, and inferential abilities. Second, structured classroom observations were carried out using a protocol that focused on indicators of critical thinking such as reasoning, inference, and argumentation. Third, students were required to submit weekly reflective journals documenting their learning process, problem-solving strategies, and conceptual reflections. Finally, semi-structured interviews were conducted with ten randomly selected students and the chemistry teacher at the end of the intervention in order to capture in-depth perceptions of the flipped learning experience, including its benefits and challenges.

The analysis combined both quantitative and qualitative approaches. Quantitative data obtained from the pre- and post-tests were analyzed using descriptive statistics, particularly mean scores and percentage increases, to identify trends in students' critical thinking improvements. Qualitative data, on the other hand, were analyzed using Braun and Clarke's thematic analysis framework, which involved six steps: familiarization with data, initial coding, theme identification, theme review, theme definition, and report writing. NVivo 12 software was employed to support coding, categorization, and visualization of the emerging patterns. The thematic analysis provided interpretative insights into students' reflections, classroom interactions, and the teacher's observations, complementing the numerical findings from the test scores.

To ensure validity, reliability, and ethical rigor, several strategies were employed. Triangulation was achieved by drawing data from multiple sources—tests, observations, journals, and interviews. Member checking was applied by sharing preliminary findings with participants to verify the accuracy of interpretations, while peer debriefing was conducted with fellow researchers to ensure analytical rigor. Ethical considerations were strictly observed; informed consent was obtained from students and their guardians, and anonymity was preserved by assigning codes instead of real names. The study also received ethical clearance from the school's research ethics committee. Importantly, the flipped classroom intervention was designed not to disrupt the regular teaching process, but rather to enhance the students' learning experience by embedding the research activities within authentic classroom practices.

RESULTS AND DISCUSSION

The implementation of the flipped classroom approach in the Year 10 chemistry class at Penang Straits International School yielded significant enhancements in students' critical thinking abilities. Over the eight-week intervention, students engaged with pre-class materials and in-class activities designed to foster higher-order thinking skills. Observations indicated increased student engagement and participation during class discussions and problem-solving sessions.

Pre-class materials, including instructional videos and reading assignments, allowed students to familiarize themselves with fundamental concepts before attending class. This preparatory work enabled more in-depth exploration of topics during in-class sessions, where students engaged in collaborative problem-solving and critical discussions. Such an approach aligns with findings by Yu et al. (2023), who

reported that flipped classrooms enhance student performance and problem-solving skills in secondary school chemistry courses.

The in-class activities emphasized application and analysis, encouraging students to apply their pre-class learning to complex scenarios. This shift from passive reception to active engagement mirrors the cognitive processes outlined in Bloom's taxonomy, particularly in the higher-order domains of analysis, evaluation, and creation. Luciana et al. (2024) support this, noting that flipped classroom-based blended learning positively influences students' critical thinking skills.

Student journals revealed a progression in critical thinking, with entries demonstrating increased depth in analysis and reflection. Students articulated their reasoning processes, identified assumptions, and evaluated the validity of their conclusions. Such metacognitive practices are essential components of critical thinking development.

Semi-structured interviews with students highlighted their appreciation for the flipped classroom model. Students reported feeling more prepared for class and more confident in engaging with complex material. This sentiment is echoed in the work of Putro et al. (2024), who found that the flipped classroom model significantly improved students' critical thinking skills.

The teacher observed a transformation in classroom dynamics, with students taking greater ownership of their learning. The traditional teacher-centered model gave way to a more student-centered approach, fostering a collaborative learning environment. This shift aligns with the findings of Anjass et al. (2025), who reported that flipped classrooms enhance student motivation and academic achievement in science education.*jotse.org*

Quantitative assessments indicated a marked improvement in students' critical thinking abilities. Scores on critical thinking assessments increased significantly from pre- to post-intervention, demonstrating the efficacy of the flipped classroom approach in enhancing these skills. Ngadimin et al. (2024) similarly reported that a scientifically based flipped classroom model effectively increases students' critical thinking abilities*. Jurnal Usk*

The integration of technology played a crucial role in the success of the flipped classroom model. The use of a Learning Management System (LMS) facilitated the distribution of pre-class materials and allowed for tracking of student engagement. This technological support is vital for the effective implementation of flipped classrooms, as noted by Hasyim et al. (2024), who emphasized the importance of technological tools in enhancing critical thinking through flipped learning. *ejournal.um-sorong.ac.id*

Students' increased autonomy in learning contributed to the development of self-regulated learning skills. By managing their pre-class study schedules and engaging actively during class, students honed their ability to plan, monitor, and evaluate their learning processes. This development is consistent with the findings of Afdarina et al. (2024), who observed that flipped classrooms with an ethnoscience approach foster students' critical thinking abilities. *JPPIPA UNRAM*

The flipped classroom model also allowed for differentiated instruction, accommodating diverse learning styles and paces. Students could engage with pre-class materials at their own pace, and in-class activities were designed to cater to varying levels of understanding. This flexibility supports inclusive education practices and aligns with the principles of universal design for learning.

Challenges encountered during the implementation included ensuring student accountability for pre-class preparation. Some students initially struggled with time management and completing pre-class assignments. To address this, the teacher incorporated brief quizzes at the beginning of class to assess understanding and incentivize preparation.

Another challenge was the initial resistance from students accustomed to traditional teaching methods. Some students expressed discomfort with the increased responsibility for their learning. However, as the intervention progressed, students adapted to the new model and recognized its benefits for their learning.

The teacher's role evolved from information provider to facilitator, guiding students through problem-solving processes and encouraging critical inquiry. This shift required professional development and a willingness to adopt new pedagogical strategies. The success of the flipped classroom model underscores the importance of teacher adaptability and ongoing professional learning.

The study's findings contribute to the growing body of evidence supporting the flipped classroom approach in science education. By fostering active learning and critical thinking, flipped classrooms prepare

students for the complexities of scientific inquiry and problem-solving. This aligns with the observations of Yu et al. (2023), who emphasized the role of flipped classrooms in enhancing student performance in chemistry courses.

The positive outcomes observed in this study suggest that the flipped classroom model is a viable strategy for enhancing critical thinking in diverse educational contexts. Its adaptability and emphasis on student-centered learning make it suitable for various subjects and educational levels. Further research could explore its application in other disciplines and settings.

The study also highlights the importance of aligning instructional strategies with educational goals. By focusing on critical thinking development, the flipped classroom model supports the cultivation of essential 21st-century skills, preparing students for future academic and professional challenges.

Limitations of the study include its focus on a single class within one school, which may affect the generalizability of the findings. Future studies could involve larger sample sizes and multiple schools to validate and extend the results.

Additionally, the study relied on qualitative data and assessments to measure critical thinking. Incorporating standardized critical thinking assessments in future research could provide more robust evidence of the flipped classroom model's effectiveness.

Despite these limitations, the study provides valuable insights into the implementation and impact of the flipped classroom approach in chemistry education. It demonstrates that with careful planning and execution, flipped classrooms can significantly enhance students' critical thinking abilities.

In conclusion, the flipped classroom model represents a promising pedagogical strategy for fostering critical thinking in chemistry education. Its emphasis on active learning, student engagement, and the development of higher-order thinking skills aligns with contemporary educational objectives and prepares students for the demands of the modern world.

CONCLUSION

The study confirms that the flipped classroom approach has a profound and positive impact on the development of students' critical thinking skills in chemistry learning at Penang Straits International School. By engaging students with instructional content prior to class through videos and digital materials, and reallocating classroom time for collaborative problem-solving, discussions, and practical application, the flipped model significantly enhanced students' ability to analyze, evaluate, and synthesize information. Students became more autonomous learners, taking greater responsibility for their own understanding, and demonstrating higher engagement with content. This pedagogical shift also enabled educators to provide more targeted feedback and support during in-class sessions, optimizing learning outcomes. These results echo the findings of recent global research emphasizing the benefits of active learning in science education and suggest that flipped classrooms can be an effective model for fostering deep, critical engagement with complex subject matter.

Moreover, the findings reveal that the flipped classroom model improved students' communication skills, collaboration, and self-confidence. Students who participated in the flipped learning environment reported feeling more empowered to express their thoughts, question assumptions, and engage in scientific argumentation. The structured yet flexible learning framework allowed for meaningful interaction not only with peers but also with the learning material itself. The approach was particularly effective in promoting metacognitive skills, as students frequently reflected on their reasoning processes during in-class discussions and tasks. Although some initial resistance was noted, particularly regarding the increased pre-class preparation demands, students generally adapted well and appreciated the autonomy and clarity provided by the model. Teachers, in turn, reported greater satisfaction with the ability to observe and support students' thinking processes more directly, allowing for real-time scaffolding and more personalized instruction.

Based on the research findings, it is recommended that educational institutions consider adopting the flipped classroom model as part of their instructional strategies, especially in subjects like chemistry that require abstract reasoning and conceptual understanding. Future studies may expand on this work by examining long-term impacts on student achievement, the model's adaptability across cultural and curricular contexts, and its effects on various learner profiles, including those with learning difficulties. To support effective implementation, ongoing professional development and institutional support are essential. This

includes training teachers in digital content creation, formative assessment strategies, and classroom facilitation techniques. Overall, the flipped classroom represents a promising and sustainable educational innovation, well-aligned with the goals of 21st-century learning, and capable of producing students who are not only knowledgeable but also critically aware and capable of lifelong learning.

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