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A Review on the Effect of Technology Integration on Students' Performance in Organic Chemistry Assessments and Laboratory Activities

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ABSTRACT

This study was conducted to determine the effect of technology integration in teaching organic chemistry. Specifically, it reviewed its effect in terms of students' performance in assessments and laboratory activities. The research used in this meta-analytic review includes those that are published in a peer-reviewed journal published from 2014-2024. These were then classified into three distinct groups: videos, meetings, and applications. For developing countries like the Philippines, determining and adapting best practices in technology integration can bridge significant gaps in educational quality. Based on a thorough investigation and analysis of available research about technology integration in organic chemistry, it was found that there is no significant difference between the effect of active learning in organic chemistry for both online and in-person classes. The reasons for this advantage include effective content delivery, reduced difficulties and increased comprehension in understanding material, and drawing stronger connections between lecture topics and laboratory activities. The integration of technology in teaching organic chemistry has also shown to yield positive results, in particular via laboratory video instructions. This received increased student acceptance, especially during the pandemic. These materials had improved students' efficiency and knowledge in laboratory activities, and increased their independence in chemical techniques. A positive correlation was also found between self- concept ability and assessments; students who engaged more in interactive lectures and quizzes performed better. Interestingly, it is discovered that its effect on students' techniques and calculations was negligible. The performance of students using an application was similar to that of those using traditional approaches in problem-solving. Teachers demonstrated improved ICT skills after the pandemic. While online instruction can be a viable alternative for teaching organic chemistry, both students and teachers preferred in-person classes.

INTRODUCTION

The COVID-19 pandemic has affected life as well as education systems worldwide. It has highlighted existing challenges in the education sector like poor performance of students. Among the hardest hit are the fields requiring hands-on, experiential learning, such as organic chemistry. The abrupt shift to remote learning has challenged traditional educational models, causing a lot of difficulties as voiced out by students in the context of developing countries (Rotas & Catapay, 2020).

In the Philippines, the impact has been particularly severe. For context, Filipino students have historically faced challenges in science education even before the pandemic. This is evident in their consistently poor performance in international assessments. In the PISA 2018, Filipino learners' average science literacy scores ranked second to last among 78 countries (Bernardo, *et al.*, 2023). Despite the education department's firestorm of reforms and preparations following a dismal showing in PISA 2018, Filipino students who took the test in 2022 reached the minimum level of proficiency again. For Scientific Literacy, from 357 in 2018 to 356 in 2022 (PhilStar, 2023). The root causes of this underperformance can be traced to a combination of factors, coming from country, school, and student levels (Alivernini & Manganelli, 2015). Organic chemistry demands a robust integration of theoretical and practical learning. In fact, a survey conducted among the teachers in South Africa indicated that tutorial and laboratory sessions are the most important factors that greatly improve the performance in Organic Chemistry (Mahajan & Singh, 2005 as cited in Ramli, 2020). However, the pandemic has exposed the fragility of the existing infrastructure for both lecture-based and laboratory instruction.

To address these challenges, technology integration has emerged as a vital tool. Technology enables delivery of specific content asynchronously and external to the classroom using the affordances of pre-recorded instructional videos, an online learning management system (LMS), whiteboard voiceover (WBVO), video lecture capture (VLC) and online course textbooks (Lento, 2016; Maxeld & Hay, 2020; Steele & Schramm, 2012 as cited in Dassanayake, Hewagama & Kirk, 2021). Even before the pandemic, innovative approaches such as

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flipped classrooms were being explored, where students engage with lecture materials outside of class and use classroom time for interactive, hands-on activities. There are also a number of studies on a "flipped classroom" approach that report improvements in grades and attitudes of students (Mooring, Mitchell & Burrows, 2016; Liu, Raker & Lewis, 2018 as cited in Cooper, *et al.*, 2019; Dehgan, Horan & Frome, 2022). Teachers can provide interactive and practical experiences using digital tools even in a remote learning set-up.

This review seeks to explore the potential of technology integration to address these challenges in organic chemistry education. By systematically analyzing existing research, this review will evaluate how various technological tools and methodologies have been employed to enhance both lecture and laboratory instruction. The findings will be beneficial for improving educational outcomes, particularly in resource-constrained settings like the Philippines.

The study is anchored with the United Nation's Sustainable Development Goals (SDGs). Particularly SDG 4, which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. By exploring how technology can bridge educational gaps and foster a more resilient and effective science education system, this review will provide insights into best practices and recommend actionable steps for educators and policymakers. These strategies are essential to prepare students to meet the demands of the future, ensuring that no student is left behind due to systemic inequalities or unforeseen global crises.

MATERIALS AND METHODS

Research Design

This study employed a quantitative meta-analytic research design to synthesize findings from published studies investigating the effectiveness of technology integration in organic chemistry lectures and laboratory instruction. A random-effects model was adopted because the included studies differed in terms of instructional approaches, technological tools, educational settings, sample characteristics, and outcome measures. This model assumes that the observed effect sizes originate from a distribution of true effects and therefore accounts for both within-study and between-study variation. Subgroup analyses were also conducted to examine whether the effectiveness of technology integration varied according to the type of technology employed, such as virtual laboratories, molecular visualization software, learning management systems, simulations, and other digital learning platforms.

Data Collection

A systematic search of the literature was conducted using reputable electronic databases and peer-reviewed journals. Studies were screened according to predetermined inclusion and exclusion criteria. Eligible studies met the following conditions, the study: focused on the integration of technology in organic chemistry lecture or laboratory instruction, published in a peer-reviewed journal, and provided sufficient methodological and statistical information for analysis. Studies that lacked complete data, were not written in English, or were not directly related to organic chemistry instruction were excluded from the analysis.

Data Analysis

Data extraction was performed using a standardized coding procedure to ensure consistency and reliability. Information collected from each study included the author, year of publication, sample size, type of technology used, instructional setting, outcome measures, and reported statistical results. Descriptive statistics, including frequencies and percentages, were used to summarize the characteristics of the selected studies. The overall effectiveness of technology integration was determined by calculating pooled effect sizes using the random-effects model. Heterogeneity among studies was assessed using the Q statistic and the I^2 statistic, while publication bias was examined through funnel plots and other appropriate statistical procedures. The analyses were conducted to determine the extent to which technology integration influences student learning outcomes in organic chemistry lectures and laboratory activities.

RESULTS AND DISCUSSION

Types of Technology Integration Employed in Organic Chemistry

The widespread use of instructional videos reflects their effectiveness in presenting abstract concepts, reaction mechanisms, laboratory techniques, and analytical procedures in a more accessible and engaging manner. Previous studies have shown that instructional videos enhance student preparedness, increase confidence, and improve understanding of laboratory procedures (Nadelson *et al.*, 2014; Box *et al.*, 2015; Rose *et al.*, 2019). Likewise, student-generated videos have been found to encourage active participation and strengthen conceptual understanding through reflection and collaborative learning (Box *et al.*, 2017; Fernández *et al.*, 2023).

Table 1 summarizes the different forms of technology integration identified across the selected studies. Among the 32 technologies reviewed, video-based learning resources were the most frequently employed (37.50%), followed by synchronous online meeting platforms (31.25%) and educational applications and simulations (31.25%).

Synchronous online platforms, such as Zoom and Google Meet, became essential during the COVID-19 pandemic because they allowed instructors to maintain communication with students while facilitating immediate feedback and collaborative discussions. Research by Anzovino *et al.* (2020), Crucho *et al.* (2020), and Sunasee (2020) demonstrated that these platforms helped maintain instructional continuity despite limitations in laboratory access.

Table 1: Technology Integration Types

Type	Description	F	%
Videos	Pre-recorded lectures/tutorials	12	37.50
Meetings	Live virtual classes/discussions	10	31.25
Applications	Educational apps/simulations	10	31.25
		32	**100**

Educational applications, virtual laboratories, augmented reality tools, and learning management systems provided students with opportunities to visualize molecular structures and explore reaction mechanisms that are often difficult to understand using conventional instructional methods. Studies involving virtual laboratories, animations, and augmented reality technologies have demonstrated improvements in conceptual understanding, engagement, and motivation among learners (Talib *et al.*, 2012; Dunnagan & Gallardo-Williams, 2020; Ikhsan *et al.*, 2023; Bandeira *et al.*, 2024).

Effect on Students' Performance in Assessments

Pre-recorded lectures in organic chemistry have contributed to higher scores in student assessments (Box *et al.*, 2015; Fernández *et al.*, 2023; Nadelson *et al.*, 2014). This improvement is also evident in laboratory marks for experiments with procedures covered in the videos (Coster *et al.*, 2019; Nadelson *et al.*, 2014), as students who watched the videos demonstrated a better understanding of the concepts and methods (Box *et al.*, 2017; Chaytor *et al.*, 2017; Damo *et al.*, 2020; Malicay, 2024). This improvement is also associated with students' self-concept of ability and psychological disposition toward the subject (Liu *et al.*, 2018; Malicay, 2024). Additionally, pre-recorded lectures are beneficial for students who are unable to attend synchronous sessions (Anzovino *et al.*, 2020; Dassanayake *et al.*, 2021). However, instructional videos have been found to have limited effects on students' laboratory techniques and calculation skills (Box *et al.*, 2017), a trend similarly observed with the use of software applications (Winter *et al.*, 2020).

Chemistry instruction using technology has been shown to affect student achievement and retention (Bedamo *et al.*, 2024). Students taught using traditional approaches have shown differences in academic performance compared with those exposed to alternative instructional approaches (Mahajan & Singh, 2005; Mooring *et al.*, 2016). The use of multiple active-learning strategies, including technology-integrated instruction, may promote greater student engagement and independence in learning (Harvey & Hodges, 1999; Nickerson & Shea, 2020). A combination of asynchronous and synchronous teaching methods has been found to be effective for content delivery, active learning, and increasing student engagement (Amsad & Al-Ansi, 2024; Babinčáková & Bernard, 2024; Nickerson & Shea, 2020; Sunasee, 2020). However, both students and teachers may continue to prefer face-to-face discussion for organic chemistry (Babinčáková & Bernard, 2024; Sukmawati, 2020).

Student success is influenced by the digital resources used in instruction. Chemistry students have demonstrated positive perceptions of the use of 3D holograms (Adamov & Ninković, 2023), virtual laboratories and simulations (Chiari *et al.*, 2020; Ikhsan *et al.*, 2023; Mistry & Shahid, 2021), and specialized applications (Bandeira *et al.*, 2024; Winter *et al.*, 2020). These technologies may provide students with alternative ways of engaging with organic chemistry concepts and laboratory activities, although access to reliable internet connectivity remains a challenge (Chiari *et al.*, 2020). Additionally, the use of interactive videos and animations has been associated with improved student interest and performance (Coster *et al.*, 2019; Ngozi-Olehi *et al.*, 2018). However, challenges remain in maintaining academic integrity during online assessment (Anzovino *et al.*, 2020).

These findings suggest that technology integration can enhance organic chemistry learning by improving academic performance, supporting student engagement and independence, and providing flexible access to instructional resources. However, the effectiveness of technology appears to depend on how it is integrated with active-learning strategies and face-to-face instruction, particularly for developing practical laboratory skills that cannot be fully replicated in an online environment.

Effect on Students' Performance in Laboratory Activities

Students who watched the videos as part of their pre-laboratory instruction completed their experiments in less time (Nadelson *et al.*, 2014; Cooper *et al.*, 2019). Instructional videos were also found to increase students' understanding of experiments and promote greater independence during laboratory activities (Box *et al.*, 2015; Box *et al.*, 2017; Philippine Star, 2023; Rotas & Cahapay, 2020). Additional instructional approaches and techniques that capitalize on the use of technology may help compensate for constraints placed on the learning environment (Nadelson *et al.*, 2014; Damo *et al.*, 2020; Sunasee, 2020). Technology-supported instruction also assisted students in recognizing connections between laboratory themes and reactions and the topics covered in Organic Chemistry I lectures (Chaytor *et al.*, 2017), as connecting new knowledge to core ideas helps students develop more expert-like knowledge frameworks that can be built upon and applied in new situations (Crucho *et al.*, 2020).

Through online and blended learning, instructors were able to teach higher-order and systems-thinking skills in organic chemistry, while students were also able to develop manual skills essential for laboratory work (Babinčáková & Bernard, 2024; Sunasee, 2020). Factors influencing students' learning during the pandemic included intelligence level, teachers' creativity in instruction, and the methods used for observation and learning (Amsad & Al-Ansi, 2024). Potential solution pathways and strategies were recorded by instructors and provided to students electronically; however, practical laboratory work should be conducted in person and should not be replaced by online experiments unless absolutely necessary (Babinčáková & Bernard, 2024; Sunasee, 2020; Timofte & Popuş, 2019).

Open-access virtual inquiry-based experiments enable students to apply theoretical knowledge while fostering a dynamic online learning environment (Mistry & Shahid, 2021). Such activities can help develop skills needed for transitioning from expository laboratory activities to research-oriented projects (Chiari *et al.*, 2020; Mistry & Shahid, 2021). Additionally, technology integration through mobile applications and instructional videos can help reduce students' laboratory anxiety (Damo *et al.*, 2020).

Overall, the findings highlight the advantages of using instructional videos as part of pre-laboratory instruction. Students who engage with these resources may complete experiments more quickly while demonstrating improved understanding and greater independence during laboratory activities. Furthermore, technology-supported instructional strategies may help mitigate limitations within the learning environment and strengthen connections between laboratory activities and lecture topics in organic chemistry. Technology-integrated approaches may also support the development of higher-order thinking skills. During the pandemic, students' learning was influenced by factors such as intelligence level, teachers' creativity, and the instructional and observational methods employed (Amsad & Al-Ansi, 2024). However, although solution pathways and strategies can be provided electronically, practical laboratory work should be conducted in person whenever possible to preserve hands-on learning experiences (Babinčáková & Bernard, 2024; Sunasee, 2020).

The results indicate that technology-integrated delivery in organic chemistry significantly improves student assessment scores and laboratory marks, suggesting the integration results in improved understanding of concepts and methods among students using the resources. However, while using instructional videos improves conceptual understanding, there was little effect on student technical skills and calculation practice, a limitation also observed with software application use. The use of technology positively impacts student achievement and retention, lowering students' reliance on instructors and improving independent learning. Moreover, blended asynchronous and synchronous teaching methods prove to be effective in content delivery and engagement; however, both students and teachers prefer face-to- face interactions for the discussion of organic chemistry.

CONCLUSION

Active learning style benefits the students in learning organic chemistry in both online and in-person classes. This is attributed to effective content delivery, lesser difficulties in understanding the material, and drawing connection to the topics discussed in the lecture that was being performed in laboratory activities.

Technology integration of laboratory video instructions showed positive results in terms of students' acceptance, improved students' efficiency and knowledge in laboratory activities, and students' independence in chemical techniques. The student engagement in learning management systems showed that students tend to be more active during the pandemic.The factors attributed to the interest of students in chemistry includes level of intelligence, teachers' creativity, and learning conditions.

Positive correlation between self-concept ability and assessments was also drawn from the analysis. Students who engage more in interactive lectures and participate in quizzes perform better. Though there is a positive effect of technology integration in the teaching-learning process of organic chemistry. It was discovered that its effect in the students' technique and calculation is considered negligible. The performance of the students using the application is similar to that of the student using a traditional approach in terms of problem solving. The teachers showed an improved quality of ICT skills after the pandemic. Online instruction may be a good alternative in teaching organic chemistry, however from the students' and teachers' perception, face-to-face classes are still the preferred mode of teaching.

It would be very much suggested to study the impact of integration of AI in organic chemistry instruction and an analysis of the effects of the pandemic and the MATATAG curriculum on students' science literacy should also be conducted.

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