Jurnal Pijar MIPA
https://jurnalfkip.unram.ac.id/index.php/JPM

ISSN 1907-1744 (Print)
ISSN 2460-1500 (Online)

Enhancing Students' Understanding of Hybridization in Organic Compounds through a Flipped Classroom Approach Combined with Game-Based Learning

Najah Baroud*, Abtisam Aljarmi

Chemistry Department, Faculty of Education, University of Zawia, Libya
*e-mail: n.baroud@zu.edu.ly

Received: March 9, 2025. Accepted: March 29, 2025. Published: May 11, 2025

Abstract: This study investigates how effective it is to combine flipped classroom and game-based learning strategies for teaching the intricate subject of hybridization in organic chemistry for the third semester of Chemistry Department students, Faculty of Education, University of Zawia, academic year 2024-2024. The research involves 60 participants, who are split into two groups: a main group (MG), which was taught using the combined approach of flipped classroom and game-based learning, and a comparison group (CG), which received conventional instruction. The MG was provided with pre-class instructional videos and PowerPoint slides, which were later reinforced through engaging activities in class, including competitive games aimed at applying the concepts learned. A post-test assessing memorization and understanding of hybridization concepts indicated that the MG surpassed the CG in both aspects. The MG obtained an overall score of 73.51% on memorisation questions, in contrast to the CG's 65.00%. The Percentage gap was 8.51%. For comprehension questions, the MG achieved an impressive 85.15%, while the CG managed only 48.95%. Percentage gap 36.2%.The results indicate that the combined strategies are effective in promoting a deep comprehension of the material. Moreover, qualitative responses from a questionnaire revealed a pronounced preference for the flipped classroom and game-based learning methods, as students noted enhanced engagement and understanding. This research underscores how innovative teaching methods can enhance the quality of chemistry education, stressing that interactive and adaptable learning environments are crucial for student success. Moreover, the study recommends employing such methods in chemistry education to enhance learning outcomes and boost student motivation.

Keywords: Flipped Classroom; Game-Based Learning; Hybridization; Main Group; Organic Compounds; Qualitative Response

Introduction

Improving the quality of education influences many aspects in modern societies. States, regardless of their financial capabilities, look for better ways to enhance their educational systems. Thus, the aim of education is to equip high-quality youth for the future is a vision shared by all countries [1]. Chemistry education poses distinctive challenges due to its reliance on abstract concepts, such as atomic structure and chemical bonding, alongside algorithmic processes like mole calculations and reaction rate determinations. These complexities can often overwhelm students, highlighting the critical need for educators to incorporate relatable analogies and practical, real-world examples to enhance understanding and engagement [2]. Hybridization is a process in which the orbitals of a single atom form new orbitals of identical shape and energy, enabling the formation of chemical compounds. Understanding hybridization in organic chemistry involves complex concepts such as atomic orbitals, electron configuration, and bond formation. Students need to distinguish different types of hybridization, each with unique geometries and properties. Visualizing molecular structures and comprehending how hybridization affects bonding and geometry requires spatial reasoning and practice. Additionally, connecting hybridization theory to the physical and chemical properties of compounds adds further complexity[3].Teaching these concepts can be challenging, particularly when relying solely on traditional methods, which often fail to engage students effectively. Therefore, modern, innovative strategies are essential. Combining game-based education with the flipped classroom model offers a dynamic approach to enhancing understanding.

Game-based learning fosters active participation, problem-solving, and collaboration in a fun, low-stress environment. This method provides immediate feedback, helping students assess their comprehension. Meanwhile, the flipped classroom allows students to review material independently through online resources like videos and readings before class. Class time then focuses on deepening understanding with interactive exercises, such as games, discussions, and problem-solving activities that reinforce the material. The development of technology towards all-digital is currently accelerating. As AI makes the teaching and learning process easier, educators are increasingly interested in incorporating it into their classrooms [4]. Humanity has adopted a new way of life that is inseparable from electronic devices. Technology serves as an instrument that can assist with various human needs. Humans have been able to utilize technology to simplify the performance of any tasks and jobs. It is the significant function of technology that ushers human society into the digital age. [5].

How to Cite:
N. Baroud and A. Aljarmi, "Enhancing Students Understanding of Hybridization in Organic Compounds through a Flipped Classroom Approach Combined with Game-Based Learning ", *J. Pijar.MIPA*, vol. 20, no. 3, pp. 387–393, May 2025.
https://doi.org/10.29303/jpm.v20i3.8725

This study explores the effectiveness of combining the flipped classroom and game-based learning approaches to teach hybridization. The aim is to increase students' understanding of this intricate subject, rendering it more captivating and participatory, with the end goal of elevating learning results. This could lead to enhancements in educational quality, service quality, and a decrease in education-related expenses [6]. In order to aid the teaching and learning process, "educators require a well-functioning learning plan that is conveyed to students via the curriculum. As a result, the curriculum is a key component of the learning process [7]. Modern innovative strategies in teaching and learning are essential both inside and outside classrooms. Maulidiya et al. argue that the flipped classroom strategy can address the challenges of limited in-class learning time and the disparity in students' learning styles[8].

In flipped classrooms, students receive learning materials prior to class in order to familiarize themselves with the content and engage in student-centered activities during class, which frequently involve collaboration and interaction [9]. In this regard, Akmar et al. add that this method enables students to utilize learning materials designed to visualize abstract concepts, such as reaction rates, through animations and simulations [10]. Lauren R. Holloway et al. argue that the flipped classroom structure has the potential to foster higher-order learning outcomes in large-enrollment undergraduate organic chemistry courses, and enhancing students' emotional and/or social engagement during in-class activities could broaden the impact of these module activities [11]. This body of literature underscores the effective synergy of game-based learning and flipped classroom methods to improve students' understanding of hybridization in organic compounds. The challenges and factors that educators need to consider when implementing these innovative teaching methods are emphasized. Utilizing the flipped classroom model, students engage with interactive learning materials such as videos and pre-class activities before class. This allows for the use of dynamic, interactive exercises and games during class to reinforce key concepts and provide students with enjoyable and motivating opportunities to apply what they have learned [12]. Both teachers and researchers are strongly encouraged to incorporate technology-based learning for their young learners. Moreover, the flipped classroom approach has room for further development [13].

Research Methods

This study employed a quasi-experimental design with a mixed-methods approach to analyze the effectiveness of combining flipped classrooms with game-based learning. The research was conducted with third-semester chemistry students at the University of Zawia during the 2024-2025 academic year.

Participants

A total of 60 students were divided into two groups: 40 in the main group (MG) receiving flipped classroom and game-based learning instruction, and 20 in the comparison group (CG) receiving traditional instruction.

Sampling Technique

A stratified random sampling method was used to ensure balanced representation across different academic performance levels.

Instructional Design

Flipped Classroom Preparation: Students accessed pre-recorded video lectures and PowerPoint slides via Telegram three days before class.

Game-Based Learning Activities

In-class activities included matching games, puzzle challenges, and "who answers fastest" competitions, all designed to reinforce hybridization concepts. Students are encouraged to participate more actively in the learning process by interactive media, which also enhances cognitive abilities [14]. By integrating both approaches, the aim was to maximize comprehension and deepen understanding to the highest level. At both schools and universities, collaborative learning is successfully taken into account for students' comprehension of chemistry[15].

Data Collection and Analysis

Quantitative Analysis

Post-test results were analysed using descriptive statistics to compare memorisation and comprehension performance between MG and CG.

Qualitative Analysis

A questionnaire and structured interviews assessed student engagement, preferences, and perceived effectiveness of the teaching method.

In-lecture Activities

During the lecture, activities centered on game-based learning were designed to create an engaging and enjoyable environment, motivating students to respond to questions with enthusiasm and a healthy sense of competition. A card-based guessing game was introduced, with the remaining details being revealed on the back and a portion of the information displayed on one side (figure 1). A matching game was played, where students were given a set of organic compounds and tasked with matching each compound to its correct type of hybridization and geometric shape. In addition to a "who answers fastest" game and some puzzle games, along with other games.

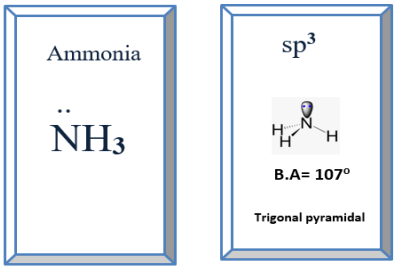

Figure 1: example of card-based guessing game

Traditional Approach

The same content was covered in another lecture, but this time using the chalkboard method, and incorporating some simple teaching aids.

Descriptive Quantitative Approach

The post-test was conducted at the end of the activity lecture, consisting of 13 questions (Tables 1 and 2) that focused on key concepts of organic compound hybridization. The assessment measured and compared the percentage of correct answers between the groups. The use of tables to present these results underscores the study's quantitative nature.

Descriptive Qualitative Approach

A qualitative descriptive analysis technique is used in the data analysis process, which entails describing, explaining, or characterizing the data in issue formulations across several stages using intelligible language and sentences [16]. The questionnaire was a crucial tool for qualitative analysis, offering valuable insights into students' attitudes toward the teaching method [17]. Their level of comprehension and their preferences compared to traditional approaches. It also explored the reasons behind these preferences. A Google Forms link, sent via email, included multiple-choice and opinion-based questions (Figure 3). Obtaining students' opinions on the teaching method under study through direct questioning (a brief interview) proved to be highly impactful. Their responses were natural and sincere, offering authentic insights into their feelings about the method.

Observation and Engagement Metrics

The researcher noted that all students watched the instructional video and expressed strong interest in exploring this innovative teaching method, hoping it would enhance their learning. Many students shared video clips, provided feedback, and suggested additional content to deepen their understanding. They showed enthusiasm for the interactive games, actively engaging with the material and eagerly answering questions. Some students even prepared their own questions based on the shared videos, which they discussed with peers.

Results and Discussion

Qualitative Analysis

To ensure accurate collection and analysis of the results, the exam was administered separately to both student groups. This approach allowed for a clear comparison of the test outcomes between the two groups. The questions categorized into two types: comprehension questions and memorization-based questions. The assessment was unannounced, as the researcher did not inform the students in advance, enhancing the reliability of the results. The percentage of correct answers for each group is presented in Tables 1 and 2.

Table 1: The percentage of correct answers for the memorization questions for MG and CG

Memorization Questions	Choices	% of correct answer MG*	% of correct answer CG**
1- Which of the following hybridizations occurs in a methane (CH_4) molecule?	sp sp^2 sp^3 no hydridization	84.2	83.5
2- How many sigma bonds are there in an ethyne (C_2H_2)?	2 3 4 No sigma bonds	74.6	70
3- What is the type of hybridization of the carbon atoms in a benzene (C_6H_6)?	sp sp^2 sp^3 sp^3d^2	55	50
4- Which of the following molecules contains a carbon atom that is sp hybridized?	CH_4 C_2H_2 C_2H_4 C_6H_6	61.6	42.2
5-What is the molecular geometry of the ammonia (NH_3)?	Tetrahedral Trigonal Pyramidal Linear Trigonal Planar	80	73.6
6- In sp3d hybridization, how many hybrid orbitals are formed?	2 3 4 5	72.2	70.7

7- How many pi (π) bonds are present in an ethene (C_2H_4) molecule?	1 2 3 No pi bond	80	60
8- How many sigma (σ) bonds are present in an ethyne (C_2H_2)?	1 2 3 No sigma bond	66	51
9- What is the bond angle between the hybridized orbitals in sp^2 hybridization?	109° 120° 180° 107°	88	84

MG*=Main Group , CG**= Comparison Group

Table 2: The percentage of correct answers for the Comprehension questions for MG and CG.

Comprehension questions	Choices	% of correct answer MG*	% of correct answer CG**
1- Which of the following represents the main reason for hybridization in atoms?	-Maintaining the original electronic configuration. -Reducing the attraction between atoms. -Reducing the repulsion between electrons.	70.1	40.5
2- Which of the following molecules has a sp^3 hybridization with a bent molecular geometry?	H_2O CH_2Cl_2 NH_3 CH_4	88.5	50.6
3- What type of hybridization occurs in the atoms of a carbon dioxide (CO_2)?	sp(O), sp^2(C) sp^2(O), sp^2(C) sp^2(O), sp (C) no correct answer	90.1	49.3
4- How does a pi bond formed?	-Bonding electrons and participation in hybridization. -Unhybridized electrons involved in bonding. -Lone electrons involved in hybridization. -All answes are correct .	87.4	45.0
5- Which of the following statements is correct?	- A sigma bond is stronger than a pi due to the sidewise overlap orbitals - A pi bond is stronger than a sigma bond. - A pi bond and a sigma bond together are stronger than a single sigma bond.	89.2	69.5
6-The repulsion between**:**	-A lone electron pair is the least. -A bonding electron pairs is the highest. - A bonding electron pair and a lone electron pair is very high. - A lone electron pairs is the highest due to the influence by a single atom.	85.6	38.8

MG*=Main Group, CG**= Comparison Group

The overall percentage for each table can be calculated and compared based on the correct answer percentages shown in Tables 1 and 2, as follows:

$$\text{Average Percentage} = \frac{\sum \text{Individual Percentages}}{\text{Total Number of Values}}$$

Where:

∑ Individual Percentages = the sum of all the individual percentages.

Total Number of Values = the total number of values or items for which the percentages were calculated.

- Average Percentage of Table 1 (Memorization Questions)is as follows:
  Main Group (MG - Flipped Classroom & Game-Based Learning): 73.51%
  Comparison Group (CG - Traditional Method): 65.00%
- Average Percentage of Table 2 (comprehension Questions) is as follows:
  Main Group (MG - Flipped Classroom & Game-Based Learning): 85.15%
  Comparison Group (CG - Traditional Method): 48.95%

In the case of memorization questions, the performance gap between the two groups is not as pronounced as for comprehension questions, with the flipped classroom group achieving only an 8.51% advantage. However, in comprehension questions, the flipped learning group outperforms the traditional method group by a significant 36.2%. This highlights the effectiveness of

flipped classroom and game-based learning methods in fostering a deep understanding of concepts, rather than simply enhancing memorization. The larger gap in comprehension questions indicates the strong impact of flipped learning and educational games in promoting a deeper grasp of the material. A noticeable difference in the overall percentage of correct answers in the assessment test was observed between the two groups. It is important to note that the percentage of correct answers in the memorization questions was similar for both groups. This can be attributed to the fact that memorization questions require less focus or prior preparation and can easily be answered during a traditional lecture. In contrast, the comprehension questions in Table 2 show a significant disparity in correct answers. These questions demand focus and understanding of key concepts related to hybridization, which are difficult to cover thoroughly in a traditional lecture format. With the flipped classroom method, students can watch videos provided by the researcher multiple times at their own convenience, allowing them to take notes and extract important information about hybridization before the activity lecture. Additionally, other video resources can be used to further deepen their understanding. The integration of game-based learning further supported the flipped classroom group's success by encouraging students to work in independent, competitive groups, facilitating information sharing and collaborative learning. This comprehensive approach led to a more effective grasp of complex concepts compared to traditional lecture-based learning.

Game-Based Learning Activities

The questionnaire on this teaching method included 10 Likert-type questions to gather students' opinions, enabling them to express their views freely. The questions were categorized into three types as follows:

Understanding of Concepts

1-What is your level of understanding of hybridization before watching the videos ?
a. poor b. average c. good d. excellent
2- How much did the videos help you understand concepts before the lecture?
a. a little b. somewhat c. quite a bit d. very much
3-What is your level of understanding of hybridization after watching the videos ?
a. poor b. average c. good d. excellent

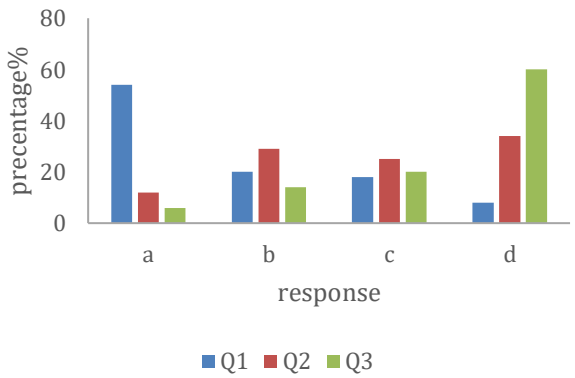

Figure 2: chart of percentage and responses of Understanding of Concepts questions

From the graph, it can be observed that the percentage difference in understanding hybridization changed significantly between before watching the video (Q 1) and after it(Q3). Most students acknowledged, to varying degrees, that these videos helped them understand more easily(Q2).

Evaluation of the Approach

1`- How fulfilled are you with the flipped classroom and game-based learning approach?
a. Unfulfilled b. Neutral c. fulfilled d. Very Fulfilled
2`- Did the flipped classroom offer more flexibility in learning?
a. strongly disagree b. neutral c. agree d. strongly agree
3`- What is your overall assessment of the flipped classroom method as a teaching tool?
a. poor b. average c. good d. excellent
4`- Do you think this method is more beneficial than traditional methods?
a. strongly disagree b. neutral c. agree d. strongly agree
5`- What is your overall assessment of game-based learning as a teaching tool?
a. poor b. average c. good d. excellent

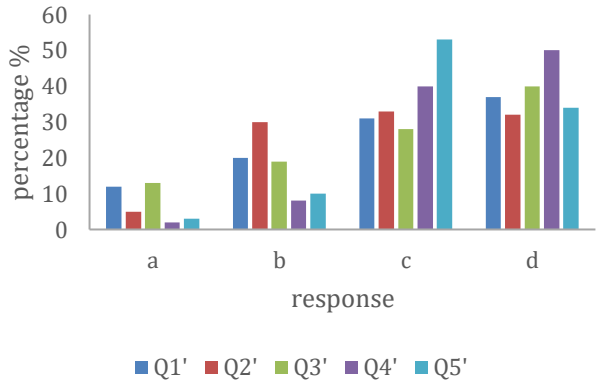

Figure 3: chart of percentage and responses of Evaluation of the approach questions

The questionnaire enabled students to assess this study, with the majority of responses emphasizing its significance and effectiveness in delivering high-quality education. It garnered an exceptionally high percentage of 'excellent' and 'good' ratings (Q1, Q3, and Q5). This is further corroborated by a substantial percentage of students who agreed that flexibility and gamification are essential for effective learning (Q2). These elements should be prioritized in future implementations to maximize educational outcomes. A clear positive trend confirms the effectiveness of these methods as viable replacements or enhancements to traditional teaching approaches (Q4). Student responses reveal that flipped classrooms and game-based learning are viewed as more effective than conventional methods.

Group Work and Interaction

1``- Is working in groups and sharing information beneficial?
a.no benefit b. some benefit c. significant benefit d. exceptional benefit
2`` - Did educational games improve your interaction with classmates?

a. strongly disagree b. neutral c. agree d. strongly Agree

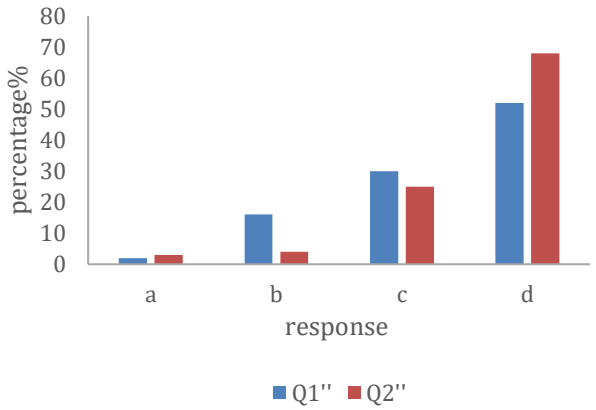

Figure 4: chart of percentage and responses of Group Work and Interaction questions

Group work (collaborating in teams) enabled students to consult one another and share information, fostering a spirit of collaboration that enhanced understanding and increased focus. Its importance was clearly reflected in the high percentage of students who agreed with it in the group work and interaction questions, particularly in questions (Q1`, Q2).

In the end of the activity lecture, the researcher asked the students a question to directly gather their opinion on this teaching method. "Do you find this teaching method useful, or do you prefer traditional methods? Please justify your answer." The most common responses were as follows:

- "Yes, it's very useful because it gave me an idea about the topic... and when I returned to the lecture, solving the problems was very easy."
- "Yes, it's a very useful method as it gives the student enough time to understand and easily absorb and solve the information."
- "Very useful. It gave me the opportunity to understand through video clips, allowing me to watch them multiple times."
- "It's somewhat good, but more practice on many problems is necessary for better understanding."
- The method is somewhat useful."
- "It is a good method. Traditional methods have become boring and routine."
- "Both methods are fine."

Based on the general feedback, students find this approach beneficial, particularly for understanding and reviewing the material. However, some students emphasize the need for more hands-on experience to fully grasp the content. In contrast to the traditional lecture-based approach, students in flipped classrooms study new content at home before applying it in interactive, practical ways in class[18]. Since traditional methods are seen as less engaging, the comparison with this more flexible and interactive approach highlights a clear preference for it.

Conclusion

The study indicates that combining the flipped classroom approach with game-based learning can significantly enhance students' comprehension of hybridization in organic chemistry. Compared to those who received traditional instruction, students using this method achieved significantly higher scores in memorization (73.51% vs. 65.00%) and comprehension (85.15% vs. 48.95%). The findings demonstrate that interactive, student-centered learning strategies are effective in improving conceptual mastery. Qualitative feedback demonstrated a robust student preference for the flipped classroom and game-based approach, pointing to heightened engagement and motivation. This research promotes the wider application of blended learning in chemistry teaching and proposes investigating its effects on additional scientific fields. The main goal of the flipped classroom approach in this particular classroom is to "transform the teacher's role from a primarily didactic function focused on instruction and demonstration of subject matter to a facilitative role that guides and supports students in their learning journeys[19]. By engaging in active, collaborative learning in class and connecting with multimedia resources before class, students developed a better respect and love for organic chemistry[20].

Author's Contribution

Najah Baroud: Drafting the research design and writing the paper. Abtisam Aljarmi: Determining the type of analysis and data analysis techniques.

Acknowledgements

The researchers sincerely thank the students of the 3rd semester of the academic year 2024-2025 for their invaluable contributions and assistance during this research. This work would not have been completed without their support. We greatly value their dedication to the project and their constant eagerness to assist us in reaching our academic objectives.

References

[1] M. Fatimah, M. Mustofa, R. P. Putra, M. M. A. Zinah, and M. Masuwd, "Optimization of the principal's role as a supervisor to improve the performance of teachers in Surakarta," *Profetika: Jurnal Studi Islam*, vol. 24, no. 02, pp. 207–216, 2023. https://doi.org/10.23917/profetika.v24i02.1986.

[2] Y. B. Yazidul, Z. Zainuddin, and M. Masuwd, "E-Magazine trial design with a social emotional learning approach using Kvisoft Flipbook software in Madrasah," *Al-Insyiroh: Jurnal Studi Keislaman*, vol. 10, no. 2, pp. 364–384, 2024. https://doi.org/10.35309/alinsyiroh.v10i2.306.

[3] G. Lamoureux and J. F. Ogilvie, "A Critical History of Hybrid Atomic Orbitals and Hybridization," J. Chem. Rev., vol. 22, no. 3, pp. 330-720, 2022, https://doi.org/10.22034/jcr.2022.330720.1144

[4] N. Baroud, K. Alouzi, Z. Elfzzani, N. Ayad, and H. Albshkar, "Educators' perspectives on using AI as a content creation tool in Libyan higher education: A case study of the University of Zawia," *JERIT: Journal of Educational Research and Innovation Technology*, vol. 1, no. 2, pp. 61–70, 2024. https://doi.org/10.34125/jerit.v1i2.12

[5] R. Rilnando and M. Masuwd, "Teacher opportunities and challenges in the digital era," *Review of International Journal Social Issues (RIJOS)*, vol. 1, no. 1, pp. 22–32, 2024.

[6] R. Firdaus, S. Fahmi, A. Sunarno, Fadhillah, and M. Masuwd, "Improving the quality of education through quality of service and education costs," *Nidhomul Haq: Jurnal Manajemen Pendidikan Islam*, vol. 9, no. 3, pp. 756–768, 2025. https://doi.org/10.31538/ndhq.v9i3.63.

[7] R. Ruslan, N. Faijah, L. Luthfiyah, and K. M. Alouzi, "Facing The Independent Curriculum: Teacher Challenges And Strategies In The Evaluation Of Islamic Religious Education Learning," Jurnal At-Tarbiyat: Jurnal Pendidikan Islam, vol. 7, no. 2, pp. 247, 2024, doi: 10.37758/jat.v7i2.861.

[8] L. Maulidiya and D. Novita, "Development of E-Worksheet inquiry-flipped classroom on chemical equilibrium material to improve students' analytical thinking skills," *Jurnal Pijar Mipa*, vol. 19, no. 4, pp. 649–656, 2024. https://doi.org/10.29303/jpm.v19i4.6939.

[9] R. Deng, S. Feng, and S. Shen, "Improving the effectiveness of video-based flipped classrooms with question-embedding," *Educ. Inf. Technol.*, vol. 29, pp. 12677–12702, 2024. https://doi.org/10.1007/s10639-023-12303-5.

[10] R. Akmar, M. Mawardi, A. Ulianas, and F. Qurrata Aini, "Effectiveness of Discord instructional media integrated with flipped classroom and guided inquiry learning on reaction rates on students learning outcomes," *Jurnal Penelitian Pendidikan IPA*, vol. 10, no. 1, pp. 108–115, 2024. https://doi.org/10.29303/jppipa.v10i1.6385.

[11] L. R. Holloway et al., "Using flipped classroom modules to facilitate higher-order learning in undergraduate organic chemistry," *J. Chem. Educ.*, vol. 101, no. 2, pp. 490–500, 2024. https://doi.org/10.1021/acs.jchemed.3c00907.

[12] B. Tang, "Combining game-based learning and flipped classroom - An analysis based on affordance theory," *J. Educ. Humanit. Soc. Sci. RETPS*, vol. 22, p. 722, 2023.

[13] A. Assi and A. Cohen, "Context-based learning in flipped middle school chemistry class," *Int. J. Sci. Educ.*, vol. 46, no. 6, pp. 570–589, 2024. https://doi.org/10.1080/09500693.2023.2250067.

[14] C. Choirudin, M. Lubis, and M. A. Masuwd, "Enhancing high school students' mathematical problem-solving skills through interactive media: A classroom action research approach," *J. Teach. Learn. Math.*, vol. 2, no. 2, pp. 104–121, 2025. https://doi.org/10.22219/jtlm.v2i2.31685.

[15] H. Beskara and A. Wiyarsi, "A systematic review: How the implementation of collaborative learning in chemistry?", *J. Pendidik. Kimia Indonesia*, vol. 8, no. 1, pp. 39–50, 2024. https://doi.org/10.23887/jpki.v8i1.67178.

[16] P. Paisun, S. Syarifah, and M. Masuwd, "Investigating the relationship between teacher self-efficacy and student achievement," *Andragogi: Jurnal Pendidikan dan Pembelajaran*, vol. 4, no. 2, pp. 94–108, 2024. https://doi.org/10.31538/adrg.v4i2.1303.

[17] N. Baroud, "A systematic comparison of students' attitudes toward practical work in chemistry department, Faculty of Education, Zawia-University of Zawia," *Int. J. Chem. Educ. Res. (IJCER)*, pp. 137–143, Oct. 16, 2024. https://doi.org/10.20885/ijcer.vol8.iss2.art7.

[18] M. M. Haruna, C. S. Tukura, F. M. Sobowole, and L. A. Fadipe, "Influence of flipped classroom models on pre-service teachers' attitude towards chemistry in colleges of education in North-Central, Nigeria," *Custech Int. J. Educ.*, vol. 1, no. 1, pp. 385–401, 2024

[19] M. N. Sarwar et al., "Fostering conceptual understanding of photocatalysis for sustainable development: A social constructivism flipped-classroom model," *Sustainability*, vol. 16, no. 23, pp. 10324, 2024. https://doi.org/10.3390/su162310324.

[20] E. Nsabayezu, O. Habimana, W. Nzabalirwa, and F. Niyongabo Niyonzima, "Influence of multimedia-supported flipped classroom approach on students' attitudes toward learning organic chemistry," *Int. J. Pedagogy Curric.*, vol. 32, no. 1, pp. 107–139, 2024. https://doi.org/10.18848/23277963/CGP/v32i01/107-139.