International Journal of Evaluation and Research in Education (IJERE)
Vol. 14, No. 6, December 2025, pp. 4364~4374
ISSN: 2252-8822, DOI: 10.11591/ijere.v14i6.32823

Tailoring collaborative learning with jigsaw and VARK: a case study in teaching physics with environmental protection

Ngan Hai My Le[1], Anh Thi Kim Nguyen[2]
[1]Faculty of Physics, Ho Chi Minh City University of Education, Ho Chi Minh City, Vietnam
[2]Graduate Institute Digital Learning and Education, National Taiwan University of Science and Technology, Taipei City, Taiwan

Article Info

Article history:

Received Sep 13, 2024
Revised Jul 1, 2025
Accepted Jul 28, 2025

Keywords:

Collaborative learning
Collaborative skills
Jigsaw strategy
Learning styles
VARK model

ABSTRACT

Collaboration is a crucial 21st century skill, requiring learning environments that foster teamwork while leveraging students' individual strengths. This study aimed to enhance collaboration using the jigsaw strategy, which was adapted to students' learning styles based on the model: visual, aural, read/write, and kinesthetic (VARK). The study involved 27 tenth-grade students in Ho Chi Minh City and focused on the topic "physics with environmental protection." Students were initially grouped by learning styles into expert groups and later reorganized into mixed jigsaw groups to collaboratively address tasks related to environmental issues. A quasi-experimental design was employed, utilizing pre- and post-test self-assessment surveys, video observations, and group discussions to assess collaborative performance. Quantitative data were analyzed using the Wilcoxon signed rank test, while qualitative data provided deeper insights. Results demonstrated a significant improvement in team support (p=0.030), suggesting that aligning learning tasks with students' styles foster group cohesion. However, participation and contribution showed minimal improvement, with students preferring reading/writing styles facing challenges in adapting to group activities. While the integration of jigsaw and VARK proved effective in enhancing collaboration, the study underscores the need to develop strategies to accommodate diverse learning preferences. Future research should involve larger sample sizes and consider teachers' perspectives to optimize the practical implementation of learning styles in collaborative learning environments.

Corresponding Author:

Ngan Hai My Le
Faculty of Physics, Ho Chi Minh City University of Education
280 An Duong Vuong, Cho Quan Ward, Ho Chi Minh City, Vietnam
Email: nganlhm@hcmue.edu.vn

1. INTRODUCTION

Collaboration skills are essential for leaners to adapt to the evolving demands of society and the workforce [1]. In 21st-century education, fostering student collaboration skills is a key priority that requires focused attention from educators [2]–[4]. Collaborative learning fosters an interactive environment in which students develop mutual responsibility and shared benefits, enhancing their teamwork skills [5], [6]. Research suggests that effectively implementing collaborative learning requires meeting specific conditions [6], [7]. Specifically, individuals in a group should exhibit positive interdependence, engage in direct interaction, take responsibility for shared tasks, develop teamwork skills, and perform self-assessment throughout the collaboration process [6], [7]. Collaboration effectiveness is primarily influenced by learners' awareness, engagement, and contributions. Therefore, collaborative teaching should foster a supportive environment, encourage active participation, and provide structured tasks that develop essential teamwork and interpersonal skills [8], [9].

Collaborative learning offers a practical framework for developing teamwork skills; however, its effectiveness is influenced by individual learning styles [3]. Aligning instructional strategies with students' learning styles can enhance collaborative engagement by catering to their preferred modes of receiving and processing information. Research by Kayes *et al.* [10] underscores the crucial role of learning styles in identifying differences and similarities among group members, which significantly shape the collaborative process. A learning style refers to an individual's preferred way of receiving and assimilating new knowledge [11]–[13]. Research indicates that tailoring teaching methods to students' learning styles enhances engagement, improves attention, facilitates information processing and retention, and significantly boosts learning outcomes [14], [15]. Given its impact on learning effectiveness, learning style is a critical factor to consider when designing learning activities, particularly in collaborative learning [16], [17]. Research by Putri *et al.* [14] further emphasizes the significance of understanding students' learning styles, particularly in science education, where these insights facilitate knowledge acquisition and enhance learning accessibility. Integrating learning styles into science instruction has significant potential to enhance student outcomes and maximize individual learning potential.

Various models for diagnosing student learning styles have been introduced in education, with the visual, aural, read/write, and kinesthetic (VARK) model by Fleming [18] being one of the most widely recognized. Fleming [18] defines learning styles as an individual's preferred way of acquiring, processing, and organizing information. The VARK model categorizes learning styles based on sensory preferences, including visual, auditory, reading/writing, and kinesthetic [18]. This model has received considerable attention from researchers, particularly in science education, where it has demonstrated promising results in enhancing student engagement and learning outcomes [17], [19], [20]. For instance, Sintia *et al.* [16] conducted an experimental study with 50 high school students, where the experimental group consisted of students with diverse VARK learning styles, resembling the jigsaw group structure. The findings revealed that students who received instruction aligned with their learning styles exhibited higher academic performance [16].

According to Troussas *et al*. [21], assessing and flexibly applying learning styles can optimize learner engagement and satisfaction in a collaborative learning environment. The jigsaw strategy is one of the most widely adopted strategies for collaborative learning, particularly in teaching scientific content that involves exploring multiple dimensions [22]–[24]. Numerous studies have highlighted the jigsaw strategy's effectiveness in fostering collaboration skills and improving student learning outcomes by promoting individual responsibility for knowledge sharing [23]–[25]. Research indicates that the jigsaw strategy facilitates meaningful interactions among group members and encourages individual contributions to group success [26], [27]. However, a key challenge lies in forming balanced student groups that align with each learner's unique characteristics [25]–[27]. To address this, several studies have investigated integrating VARK learning styles into group formation to optimize interaction and collaboration [28]. This approach enhances group dynamics, enabling students to leverage their strengths for more meaningful contributions [29].

While collaborative learning and learning styles have been extensively studied, most research examines them separately. Prior studies highlight the effectiveness of jigsaw in fostering collaboration [21]–[23] and VARK in personalizing instruction [16], [18], [19]; however, limited research integrates these methods within a structured collaborative framework. Moreover, collaborative learning has been primarily explored in higher education, with limited attention given to secondary education [1]. Given its significance in cognitive and social development, further investigation at the school level is necessary, particularly in subject-specific contexts such as science education.

This study examined the impact of structuring jigsaw-based collaborative learning around learning styles on students' collaboration skills in a physics context. Beyond addressing this gap, the study offers insights into optimizing collaborative learning in science education. Specifically, it aimed to answer the following research question: How does the jigsaw strategy influence students' collaboration skills when structured according to their learning styles? The findings offer empirical evidence on the benefits and challenges of integrating learning styles into collaborative learning in secondary education, informing future science teaching applications.

2. METHOD

2.1. Theoretical framework

The study employed the VARK questionnaire, an online tool comprising 16 concise multiple-choice situational questions, to efficiently assess students' preferred learning styles [30]. This instrument categorized students into one of four learning style groups-visual, auditory, reading and writing, and kinesthetic-based on their responses. The questionnaire results categorized students based on their dominant learning styles.

The research integrated the VARK model with the jigsaw strategy by grouping students based on their identified learning styles. To align with the VARK model, learning materials were customized to each learning style. Visual learners engaged with diagrams and images, auditory learners focused on listening tasks, kinesthetic learners participated in hands-on activities, and reading/writing learners worked with text-based content. This approach enables students to process data according to their strengths. Figure 1 illustrates the theoretical framework of this study. The research adopted the task-centered teaching model proposed by Merrill [31], which emphasizes breaking down a primary task introduced at the beginning of a lesson into smaller, manageable sub-tasks. Students were reorganized into jigsaw groups after mastering their assigned content in expert groups. Each member, now an "expert", shared their knowledge with peers from different learning style groups. This structure facilitated diverse information exchange, allowing students to teach and learn from one another. Consequently, they reinforced their understanding and addressed knowledge gaps through collaborative discussion. In the final phase, students applied their acquired knowledge to solve practical, real-world tasks, enhancing their learning experience and ensuring meaningful learning outcomes.

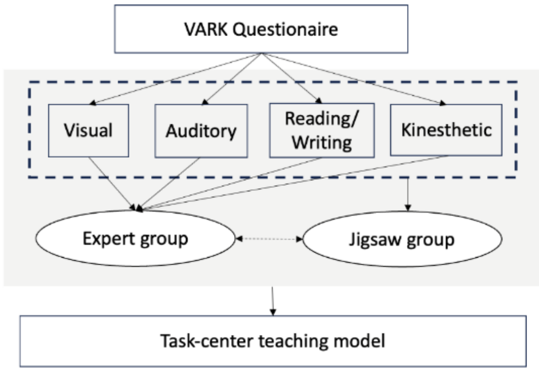

Figure 1. Collaborative learning organization process applying the jigsaw strategy

2.2. Research design

This study employed a quasi-experimental design to examine the impact of integrating the jigsaw strategy and VARK learning styles on students' collaborative skills in physics education. The research focused on the topic "physics and environmental protection", a topic in the Vietnamese high school curriculum encompassing multiple dimensions: environmental protection, fossil fuels, renewable energy, and pollution. The instructional process was structured into three units, each addressing a specific theme. The first unit explored the principles of environmental protection, the second compared fossil fuels with renewable energy, and the third evaluated energy efficiency. Learning activities in each unit were designed to align with the VARK model, allowing students to engage in tasks suited to their preferred learning styles. For instance, visual learners worked with diagrams, auditory learners participated in listening exercises and discussions, kinesthetic learners engaged in hands-on activities, and reading/writing learners analyzed and produced text-based content. These activities aimed to enhance students' ability to process information effectively, contribute meaningfully to group tasks, and apply their knowledge to real-world issues. Figure 2 presents a detailed implementation plan for the three learning units, each emphasizing different aspects of energy and environmental protection within the physics education curriculum.

2.3. Participants

The case study methodology is appropriate for this research, as it enables an in-depth analysis of student collaboration in an authentic learning environment [32]. The study analyzed student interactions, performance, and perceptions using quantitative self-assessment surveys, qualitative video observations, and group discussions. By integrating the VARK model with the jigsaw strategy, this study provides insights into how personalized grouping strategies influence collaboration skills, offering practical implications for cooperative learning in science education.

In case study approach, non-probability sampling is often utilized to explore a specific educational setting in depth [33]. Non-probability sampling is commonly used in case studies due to the focus on real-world contexts and practical feasibility rather than broad generalizability. In this study, convenience sampling was applied, selecting a readily available class of 27 tenth-grade students from a school in Ho Chi Minh City, Vietnam, with a gender distribution of 40.7% male and 59.3% female, as illustrated in Figure 3 [33].

At the beginning of the study, all students completed the VARK questionnaire to identify their preferred learning styles, which were categorized into VARK groups. Based on these results, students were initially assigned to expert groups according to their learning styles, allowing them to maximize their strengths in specific tasks. They were later reorganized into jigsaw groups, ensuring a mix of learning styles to facilitate diverse perspectives and knowledge sharing. Although the sample size may limit the generalizability of the findings, the study offers valuable insights into the feasibility of integrating collaborative learning strategies with learning styles in real classroom settings.

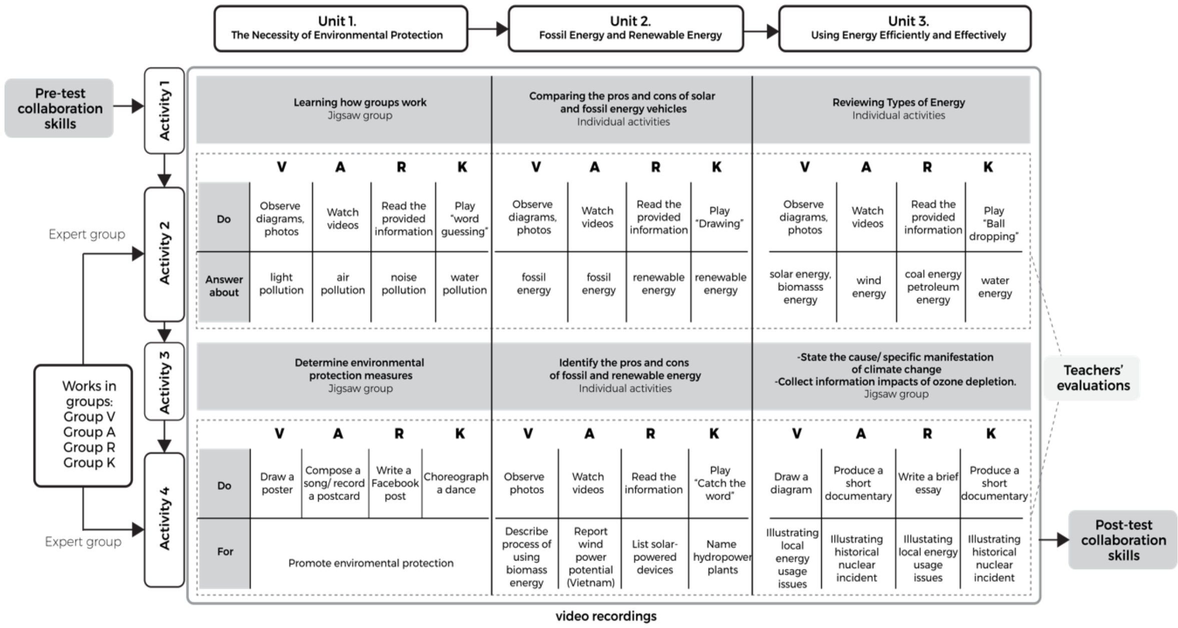

Figure 2. Plan to elaborate detailed learning activities in research

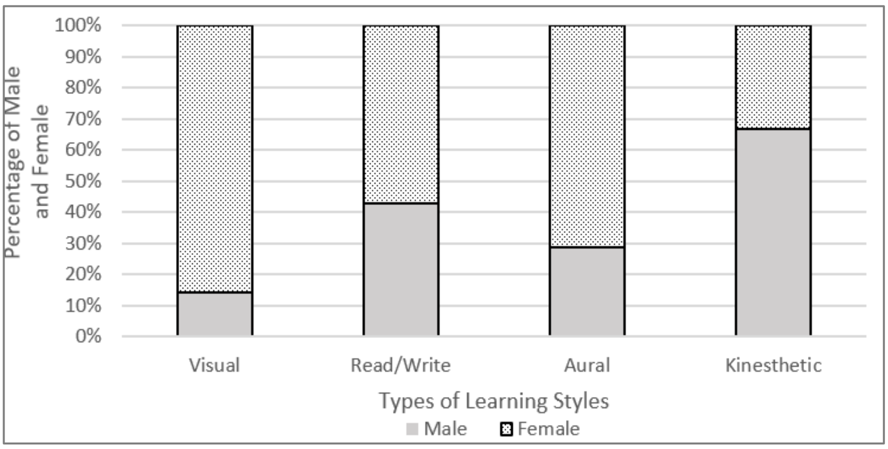

Figure 3. The ratio of male and female students in each learning style

2.4. Data collection

This research employed a mixed-methods approach, integrating quantitative and qualitative data to comprehensively evaluate the intervention. Quantitative data were collected through a self-assessment scale (ranging from level 1 to level 4), which students used to evaluate their collaboration skills before and after the unit. This scale was adapted and translated from the work of Ofstedal and Dahlberg [34]. The original version assessed ten collaboration skill components based on educator research and was modified to better align with the study's objectives and participants. The final version evaluated seven key components: contribution, participation, quality of work, time management, group support, preparation, and evaluation.

Students completed the survey both before and after the intervention to measure changes in their collaborative abilities. Observational data were gathered through both panoramic and group-specific video recordings to capture real-time interactions and behaviors during group activities. Qualitative data were obtained through group discussion sessions held at the end of each learning unit, providing deeper insights into students' perceptions of their roles, challenges faced, and the effectiveness of the group dynamics. Additionally, teachers' evaluations of group outputs, such as posters, essays, and creative projects, were included in the qualitative analysis.

2.5. Data analysis

Data analysis was conducted using both quantitative and qualitative approaches to ensure a comprehensive evaluation of the intervention. Quantitative data were analyzed using the Wilcoxon signed rank test, a robust non-parametric method designed to assess differences in paired datasets. This test was utilized to compare pre- and post-intervention score across seven dimensions of collaboration skills: contribution, participation, quality of work, time management, group support, preparation, and evaluation. This statistical method accurately measured changes in collaborative competencies, accounting for the non-normal distribution of the data.

A systematic thematic approach was used for qualitative analysis. Observational data from panoramic and group-specific video recordings were transcribed and coded to identify key themes related to group dynamics, including role distribution, mutual support, and interaction effectiveness. Similarly, notes from group discussion sessions were analyzed to uncover patterns in students' perceptions of their collaborative roles, challenges encountered during group activities, and strategies used to achieve group objectives. This qualitative analysis provided nuanced insights into the collaborative processes, complementing the quantitative findings and enriching the overall understanding of the intervention's impact.

3. RESULTS AND DISCUSSION

3.1. Student self-assessment of collaboration skills

The results in Table 1 revealed a significant improvement in the "team support" category. The pre-test mean for team support was 2.67 (SD=0.877), increasing to 3.04 (SD=0.698) in the post-test, with a significance value of 0.030 at a 95% confidence level. This improvement suggests that students' ability to support one another was substantially enhanced following the intervention. The finding demonstrates the jigsaw strategy's positive impact on fostering team support among students. In contrast, other categories, including contribution (pre-test mean=3.37, post-test mean=3.37), participation (pre-test mean=2.78, post-test mean=2.85), and quality of work (pre-test mean=3.15, post-test mean=3.07), did not show significant changes. Similarly, time management showed a slight improvement from 3.00 (SD=0.920) to 3.22 (SD=0.675), with a significant value (Sig.=0.207). Reflection remained relatively stable (pre-test mean=3.15, post-test mean=3.07), with no significant difference (Sig.=0.626).

The key finding is the significant enhancement in team support, underscoring the effectiveness of the jigsaw strategy in promoting collaborative learning and team cohesion. This result aligns with the core principles of the jigsaw strategy, where each student is expected to actively participate, accumulate knowledge, and share their expertise within the group. Students reinforce their understanding and contribute to the group's success by engaging with peers from different learning styles. Ofstedal and Dahlberg [34] defined team support refers to working together to achieve common goals. Team support manifests in various forms, depending on the group's context and objectives. It involves sharing information and ideas to solve problems, encouraging participation through task division, and being willing to help each other when peers face challenges. Tailoring learning tasks to students' learning styles enhances their ability to interact effectively and fulfill their group roles, resulting in more cohesive teamwork.

Table 1. Results of the pre-test and post-test self-evaluation of the collaborative competence of students

Category	Pre-test		Post-test		Sig.
	Mean	SD	Mean	SD	
Contribution	3.37	0.742	3.37	0.629	1.000
Participation	2.78	1.086	2.85	0.629	0.764
Quality of work	3.15	0.864	3.07	0.907	0.660
Time management	3.00	0.920	3.22	0.675	0.207
Team support	2.67	0.877	3.04	0.698	0.030*
Reflection	3.15	0.770	3.07	0.675	0.626

*p<0.050

The jigsaw strategy fostered a supportive environment by grouping students with similar traits, thus promoting team support and knowledge-sharing through assigned roles [23], [25]. This study emphasized group compatibility over learning diversity, prioritizing collaboration over broader skill development. Findings clearly highlight the technique's effectiveness in enhancing cooperation, consistent with prior research [26], [27], due to its emphasis on individual accountability and collective responsibility. In this strategy, each student serves as an "expert" contributing to group success, thereby encouraging active participation and knowledge construction. However, improvements in participation, contribution, and time management were limited, indicating that while group cohesion benefits, other collaborative aspects require further exploration. This aligns with Bertucci *et al*. [35], who highlighted challenges in balancing group dynamics with individual input.

3.2. Students' collaborative performance throughout the process

The students' learning process was structured into two types of groups: expert groups and jigsaw groups. Each group was assigned research topics aligned with its members' dominant learning styles, ensuring tasks suited their strengths. Expert groups, structured according to the VARK model, enabled students to leverage their preferred learning styles while clearly defining their roles and responsibilities. A student's remark illustrates this collaborative process, "*Let me try to find music related to the environment, then K1.3 can choreograph for the whole group to dance along.*" Frequent communication among group members fostered mutual understanding, ensuring coordination in task execution and alignment with learning objectives. Clearly defined task assignments enhanced efficiency by minimizing downtime and streamlining workflow. Most students demonstrated a clear understanding of their activities, which involved mastering content and completing projects related to each lesson. This structured approach facilitated effective knowledge acquisition and strengthened group cohesion, ensuring that all members contributed meaningfully toward the group's success.

Group members expressed their contributions and participation by identifying their strengths and capabilities, as reflected in another student's remark, "*Since A2.4 can sing, let us try composing a rap, and A2.2, who is good at writing, can write the lyrics for A2.4 to sing.*" Each member's contributions were evident in the final products, including songs and rap lyrics composed and performed by the students, which received positive feedback from the teacher and praise from other groups. Students evaluated one another's efforts within the expert group, providing feedback based on their peers' contributions. For instance, in the Auditory group, students commented, "*A2.4 has a good voice*" and "*The song needs to be longer, as it is still short, and more visuals could be added.*" The kinesthetic group's feedback included, "*The dance is not synchronized because not everyone knows the moves yet*," "*The dance is not coordinated, and not all group members are involved.*"

Meanwhile, students in the visual group, drawing on their preference for visual organization and design, provided feedback such as, "*We need more annotations and bolder lines*" and "*We should use brighter colors to make the visuals more appealing.*" These observations align with the quantitative results, which suggest that students developed a stronger sense of group support when collaborating with peers who shared their learning styles. By working in groups aligned with their learning styles, students collaborated more effectively and made meaningful contributions by leveraging their strengths.

Although the jigsaw groups had a different structure and less interaction time than the expert groups, they maintained high-quality work and demonstrated substantial individual contributions. Drawing on the knowledge acquired in their expert groups, students in the jigsaw groups actively exchanged ideas to develop a shared understanding and identify the causes of climate change and various types of energy. During discussions, students proposed ideas such as, "*Our group should draw it split into two sides, one showing pollution causes like vehicles and construction, and the other side showing burning forests and dead animals both in the sea and on land*," "*We should also add types of energy like wind power or solar panels*," and "*The negative impact is on the environment, disrupting the ecological balance. The positive impact contributes to the economic development of society.*" These exchanges ensured that all members contributed meaningfully to the final group product and stayed on track to meet the project deadline. Some jigsaw group discussions centered on the activity, "*Identify positive and negative impacts of renewable energy.*" The final product analysis revealed that the jigsaw group produced a well-organized, comprehensive output, reflecting the students' ability to integrate information from multiple sources and collaborate effectively.

The teacher asked students to discuss the advantages and disadvantages of fossil fuels and renewable energy, with their outputs presented in Figure 4. They expressed their thoughts through drawings and notes. Students highlighted that while fossil fuels remain the primary energy source, they contribute significantly to pollution, greenhouse gas emissions, and sustainability concerns. In contrast, renewable energy sources such as solar and wind power are valued for their environmental benefits, lower pollution levels, and renewability. However, students also recognized the technological challenges associated with recovering and storing renewable energy. This discussion reflected a multidimensional perspective on energy types, demonstrating students' deep understanding and awareness of the issue.

The alternating structure between expert and jigsaw groups had a positive impact on students' learning. While expert groups allowed students to master content in alignment with their learning styles, jigsaw groups facilitated peer teaching and diverse knowledge exchange. This structured approach ensured that students developed both individual expertise and teamwork skills. These findings are consistent with previous studies on using the jigsaw strategy in collaborative learning. For instance, Pashler *et al.* [36] confirmed that the jigsaw strategy enhances student engagement and improves knowledge retention. Moreover, organizing collaborative learning through the jigsaw strategy ensures equal opportunities for all students to participate meaningfully, encouraging open expression of ideas and fostering inclusive group interactions [33]. While the findings demonstrate the effectiveness of integrating the jigsaw strategy with learning styles, implementing this approach in a classroom setting posed challenges. Managing multiple groups with diverse learning styles proved complex, requiring teachers to balance individual learning needs with group objectives-a challenge compounded by time constraints within a single class period. This observation echoes previous research [37], which identified time management and teacher involvement as critical factors in successful collaborative learning. To address these challenges, teachers require professional development and resources to effectively manage diverse student groups and design tasks that accommodate different learning styles [36].

After participating in the course, students expressed enthusiasm and a willingness to continue engaging in activities that involve group division based on their abilities. However, most students needed to familiarize themselves with peer assessment and relied primarily on teacher evaluations of their final products. This lack of experience led to confusion during the assessment process, with some students feeling uncomfortable with self-assessment and peer evaluation. These challenges align with findings from previous studies [1], [35], which highlight the difficulties students encounter when lacking collaborative skills. Research indicates that students often struggle with group work, time management, and structured group evaluation, largely due to teachers' limited experience and expertise in fostering collaborative learning skills.

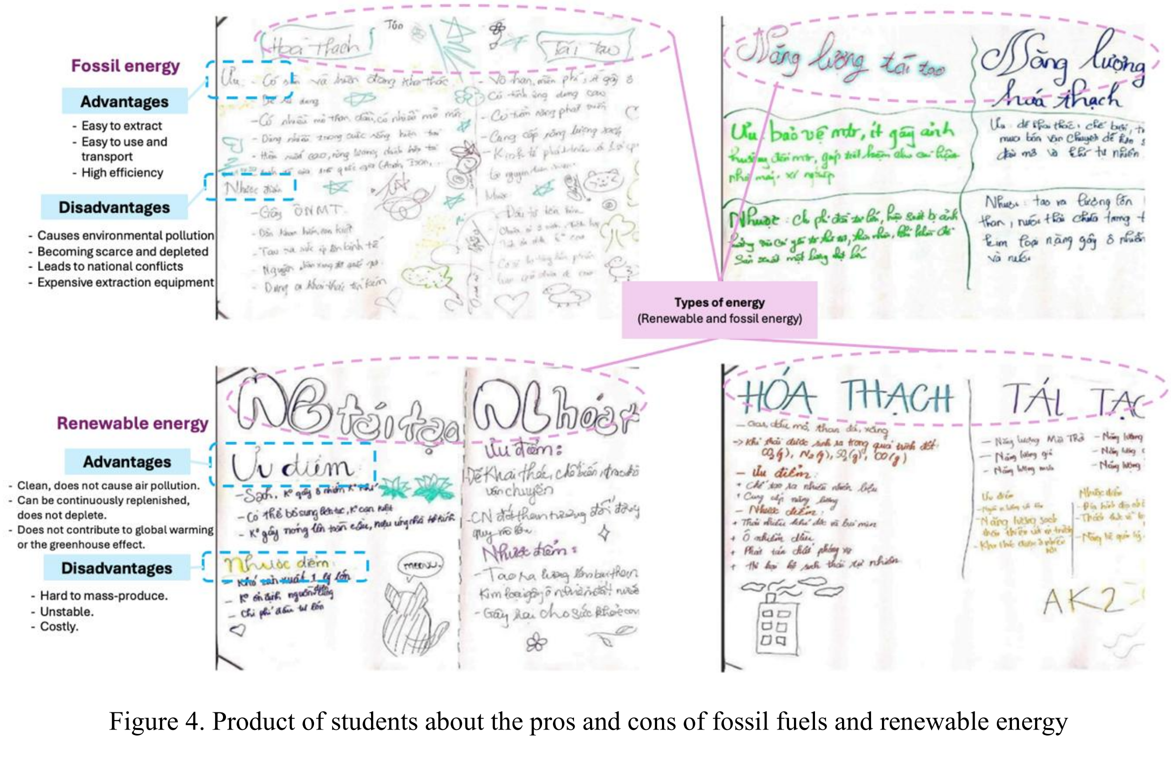

Figure 4. Product of students about the pros and cons of fossil fuels and renewable energy

3.3. Students' academic performance

In unit 1, students learn how to collaborate in groups through activity 1, which focuses on the group work process and defining each member's role. Specific tasks are assigned to each student, fostering personal accountability and ensuring that contributions align with individual strengths. In activity 2, students are grouped based on their learning styles and engage in activities related to environmental pollution.

By activity 4, they undertake more extensive creative projects such as designing posters, composing songs, writing short essays, and choreographing dances within their learning style groups to raise awareness about environmental protection. One student described their task division, "*R1.2 will summarize the tasks, R1.3 and R1.4 will assist R1.2, and I will be the group spokesperson.*" Another added, "*I will write the content and find images for part 1, R2.2 will handle part 2, and R2.3 will do part 3. We'll submit it by tomorrow night, and I'll review and summarize it.*"

Through these activities, students gain a deeper awareness of their roles and responsibilities, fostering personal accountability and strengthening their collaboration skills. By clearly dividing tasks and incorporating activities that cater to different learning styles, students can better recognize their contributions, enhancing their teamwork and problem-solving abilities. In unit 2, students are reorganized into new groups and participate in diverse interactive tasks, including discussions, information analysis, and quiz games on renewable energy sources such as biomass, wind, water, and solar power. This dynamic learning environment encourages students to apply their skills and knowledge, with one student noting, "*V1.1 and I will be responsible for both the drawing and organizing the content on the poster.*" These activities deepen students' understanding of renewable energy and reinforce the importance of collaboration in tackling complex topics.

Finally, unit 3 encourages students to use energy efficiently. The variety of activities emphasizes the importance of adaptability in learning and collaboration. The assessment evaluates the final products and the collaboration process, helping students appreciate teamwork and develop better collaboration skills. In activity 4, students continue their group work by creating diagrams, writing reports, and drafting short essays about local energy use and past nuclear accidents, providing a real-world perspective on environmental protection challenges. One student commented, "*A2.4 has a great voice and did a good job recording the song multiple times, so their participation is highly rated.*" Another noted, "*The recording should be longer, and adding more images would be ideal.*" These activities foster students' evaluation and self-reflection skills, helping them recognize their contributions and those of their peers. Through this process, students gradually enhance the overall quality of their group work.

Students performed tasks aligned with their strengths, promoting more effective collaboration. For instance, kinesthetic learners excelled in hands-on activities. Visual learners contributed meaningfully through diagrams and visual aids. The overall assessment results indicate that students with a reading/writing learning style express information primarily through written work, underscoring the need for the evaluation process to adequately recognize their efforts and contributions to group activities [38]. However, not all students benefited equally from the jigsaw approach [10]. Students with a reading/writing preference faced challenges in a collaboration model primarily driven by verbal discussions and visual representations. This finding is consistent with prior research highlighting the difficulties these learners encounter in group settings emphasizing spoken and visual elements over text-based processing [19]. These challenges underscore the importance of incorporating differentiated strategies within groups to ensure all learners feel included and empowered to contribute. Supplementary activities, such as journaling written reflections or structured text-based discussions, help ensure that reading/writing learners remain engaged and can contribute meaningfully to collaborative tasks.

The study was conducted in a large class, sometimes making it challenging for teachers to observe and support student groups due to time constraints and management difficulties. Previous studies have also highlighted the role of teachers in managing classrooms with multiple collaborative learning groups as a significant challenge, as well as discipline issues during group work and the assessment of student's performance [35], [37], [39]. To ensure the success of collaborative learning, teachers must encourage students to work together while carefully monitoring the flow of information exchanged among group members to maintain the quality of group activities and learning outcomes.

4. CONCLUSION

The study demonstrated the effectiveness of integrating the jigsaw collaborative learning strategy with the VARK learning styles model to enhance students' collaborative performance in physics education. The study provides a novel pedagogical approach that promotes personalized learning and collaborative engagement by structuring learning activities around students' preferred learning modalities and facilitating a transition from expert groups to heterogeneous jigsaw groups. The findings confirm that aligning instructional tasks with students' learning preferences significantly improves team support, reinforcing the potential of learning style-based grouping to foster cohesive and effective group interactions. Furthermore, this research extends the application of learning styles in science, technology, engineering and mathematics (STEM) education, particularly in physics and environmental protection topics, an area with limited prior empirical investigation. The study contributes to science education pedagogy by providing empirical evidence that integrating learning styles into collaborative learning models enhances student engagement and collaborative dynamics. However, despite these promising outcomes, several challenges remain.

Despite its contributions, this study has several limitations that warrant further investigation. While integrating jigsaw and VARK improved team support, students with reading/writing learning styles faced challenges in interactive, group-based tasks, suggesting the need for alternative instructional strategies to support diverse learners better. Additionally, the study was limited to physics and environmental education, leaving opportunities for future research to explore its applicability across other STEM subjects and interdisciplinary fields. Another challenge was teacher preparedness in implementing learning style-based group collaboration, highlighting the importance of teacher training programs to develop effective strategies for managing heterogeneous learning environments. Furthermore, while the jigsaw approach fosters collaboration, it may limit independent critical thinking, prompting future research to investigate hybrid instructional designs that balance teamwork with individual analytical skills. Addressing these challenges will enhance the scalability and sustainability of learning style-based collaborative learning models, ensuring effective integration into diverse educational settings.

ACKNOWLEDGMENTS

The authors would like to express their sincere gratitude to Ho Chi Minh City University of Education, Vietnam, for their support and facilitation in conducting this research. Additionally, the authors acknowledge the financial support from Ho Chi Minh City University of Education Foundation for Science and Technology.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ngan Hai My Le	✓	✓		✓			✓		✓	✓	✓	✓	✓	✓
Anh Thi Kim Nguyen		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author [NHML]. The data which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

REFERENCES

[1] H. L. J. Janssen, and T. Wubbels, "Collaborative learning practices: teacher and student perceived obstacles to effective student collaboration," *Cambridge Journal of Education*, vol. 48, no. 1, pp. 103–122, Jan. 2018, doi: 10.1080/0305764X.2016.1259389.

[2] E. Alfonseca, R. M. Carro, E. Martín, A. Ortigosa, and P. Paredes, "The impact of learning styles on student grouping for collaborative learning: A case study," *User Modeling and User-Adapted Interaction*, vol. 16, no. 3–4, pp. 377–401, Sep. 2006, doi: 10.1007/s11257-006-9012-7.

[3] M. J. Baker, B. B. Schwarz, and S. R. Ludvigsen, "Educational dialogues and computer supported collaborative learning: critical analysis and research perspectives," *International Journal of Computer-Supported Collaborative Learning*, vol. 16, no. 4, pp. 583–604, Dec. 2021, doi: 10.1007/s11412-021-09359-1.

[4] I. Warsah, R. Morganna, M. Uyun, H. Hamengkubuwono, and M. Afandi, "The impact of collaborative learning on learners' critical thinking skills," *International Journal of Instruction*, vol. 14, no. 2, pp. 443–460, 2021, doi: 10.29333/iji.2021.14225a.

[5] D. W. Johnson and R. T. Johnson, "Making cooperative learning work," *Theory into Practice*, vol. 38, no. 2, pp. 67–73, Mar. 1999, doi: 10.1080/00405849909543834.
[6] D. W. Johnson, R. T. Johnson, and K. A. Smith, "Cooperative learning: improving university instruction by basing practice on validated theory," *Journal of Excellence in College Teaching*, vol. 25, pp. 85–118, 2014.
[7] B. Liebech-Lien, "The bumpy road to implementing cooperative learning: Towards sustained practice through collaborative action," *Cogent Education*, vol. 7, no. 1, p. 1780056, Jan. 2020, doi: 10.1080/2331186X.2020.1780056.
[8] S. Ghavifekr, "Collaborative learning: A key to enhance students' social interaction," *MOJES: Malaysian Online Journal of Educational Sciences*, vol. 8, no. 4, pp. 9–21, 2020.
[9] R. M. Gillies, "Cooperative learning: Review of research and practice," *Australian Journal of Teacher Education*, vol. 41, no. 3, pp. 39–54, Mar. 2016, doi: 10.14221/ajte.2016v41n3.3.
[10] A. B. Kayes, D. C. Kayes, and D. A. Kolb, "Experiential learning in teams," *Simulation and Gaming*, vol. 36, no. 3, pp. 330–354, Sep. 2005, doi: 10.1177/1046878105279012.
[11] N. D. Fleming, "I'm different; not dumb. Modes of presentation (VARK) in the tertiary classroom," in *Proceedings of the 1995 Annual Conference of the Higher Education and Research Development Society of Australia (HERDSA)*, 1995, pp. 308–313.
[12] F. Richard and L. K. Silverman, "Learning and teaching styles in engineering education," *Engineering Education,* vol. 78, no. 7, pp. 674–681, Apr. 1988. [Online]. Available: http://117.202.29.23:8080/jspui/handle/1/297
[13] A. Slaats, H. G. L. C. Lodewijks, and J. M. M. van der Sanden, "Learning styles in secondary vocational education: disciplinary differences," *Learning and Instruction*, vol. 9, no. 5, pp. 475–492, 1999, doi: 10.1016/s0959-4752(99)00007-9.
[14] A. Putri, Yusrizal, Evendi, A. Halim, and Elisa, "The impact of learning and thinking styles on the learning outcomes of high school students," in *Proceedings of the 2nd International Conference on Science, Technology, and Modern Society (ICSTMS 2020)*, 2021, pp. 285–289, doi: 10.2991/assehr.k.210909.064.
[15] S. Yulianci, Nurjumiati, Asriyadin, and A. A. Adiansha, "The Effect of Interactive Multimedia and Learning Styles on Students' Physics Creative Thinking Skills," *Jurnal Penelitian Pendidikan IPA*, vol. 7, no. 1, pp. 87–91, Jan. 2021, doi: 10.29303/jppipa.v7i1.529.
[16] I. Sintia, H. Rusnayati, and A. Samsudin, "VARK learning style and cooperative learning implementation on impulse and momentum," *Journal of Physics: Conference Series*, vol. 1280, no. 5, p. 052032, 2019, doi: 10.1088/1742-6596/1280/5/052032.
[17] S. Subagja and B. Rubini, "Analysis of student learning styles using Fleming's VARK model in science subject," *Jurnal Pembelajaran Dan Biologi Nukleus*, vol. 9, no. 1, pp. 31–39, 2023, doi: 10.36987/jpbn.v9i1.3752.
[18] N. D. Fleming, *Teaching and learning styles: VARK strategies*. Christchurch, New Zealand: N. D. Fleming, 2001.
[19] M. Leasa, A. D. Corebima, and J. R. Batlolona, "The effect of learning styles on the critical thinking skills in natural science learning of elementary school students," *Elementary Education Online*, vol. 19, no. 4, pp. 2086–2097, Sep. 2020, doi: 10.17051/ilkonline.2020.763449.
[20] I. J. Prithishkumar and S. A. Michael, "Understanding your student: Using the VARK model," *Journal of Postgraduate Medicine*, vol. 60, no. 2, pp. 183–186, 2014, doi: 10.4103/0022-3859.132337.
[21] C. Troussas, F. Giannakas, C. Sgouropoulou, and I. Voyiatzis, "Collaborative activities recommendation based on students' collaborative learning styles using ANN and WSM," *Interactive Learning Environments*, vol. 31, no. 1, pp. 54–67, Jan. 2023, doi: 10.1080/10494820.2020.1761835.
[22] I. N. Ojekwu and B. O. Ogunleye, "Effects of Jigsaw learning strategy on science students' performance and interest in Biology in selected schools in Rivers State, Nigeria," *Sapientia Foundation Journal of Education, Sciences and Gender Studies*, vol. 2, no. 3, pp. 2734–2514, 2020, doi: 10.13140/RG.2.2.16936.60168.
[23] F. P. Soedimardjono and P. P., "Cooperative learning model with Jigsaw type improves students' sciences process skills and learning outcomes," *JPI (Jurnal Pendidikan Indonesia)*, vol. 10, no. 1, p. 172, 2021, doi: 10.23887/jpi-undiksha.v10i1.25203.
[24] A. D. M. Zuler and Y. Darvina, "Meta-analysis of the effect of the use of Jigsaw type cooperative model on student learning outcomes in learning natural science in junior high school and physics in senior high school," *Pillar of Physics Education*, vol. 14, no. 2, pp. 146–152, Nov. 2021, doi: 10.24036/11888171074.
[25] A. Şahin, "Effects of Jigsaw II technique on academic achievement and attitudes to written expression course," *Educational Research and Reviews*, vol. 5, no. 12, pp. 777–787, 2010.
[26] P. Dhull and G. Verma, "Jigsaw teaching technique for teaching science," *International Journal of Research and Analytical Reviews*, vol. 6, no. 2, pp. 809–815, 2019.
[27] N. U. Siong, S. K. B. S. Ali, and Hutkemri, "Effects of STAD and Jigsaw cooperative learning methods on badminton backhand low service skill," *International Journal of Innovation, Creativity and Change*, vol. 10, no. 10, pp. 13–30, 2020.
[28] H. Naibaho and S. Manik, "The comparative study of visual and auditory learning style on Jigsaw strategy in students reading comprehension at junior high school," *IDEAS: Journal on English Language Teaching and Learning, Linguistics and Literature*, vol. 11, no. 1, pp. 572–585, Jul. 2023, doi: 10.24256/ideas.v11i1.3802.
[29] F. R. Mulyana, D. T. Juniar, A. A. Malık, D. Mulyana, and Y. N. Hanief, "The influence of cooperative learning models and learning styles on social skills in university student," *International Journal of Disabilities Sports and Health Sciences*, vol. 7, pp. 9–18, Dec. 2024, doi: 10.33438/ijdshs.1368958.
[30] B. Prashing, "Learning styles vs. multiple intelligences (MI) two concepts for enhancing learning and teaching," *Teaching Expertise*, no. 9, pp. 8–9, 2005.
[31] M. D. Merrill, "A task-centered instructional strategy," *Journal of Research on Technology in Education*, vol. 40, no. 1, pp. 5–22, 2007.
[32] R. K. Yin, *Case study research and applications: Design and methods*. Thousand Oaks, CA: SAGE Publications, 2017.
[33] L. Cohen, L. Manion, and K. Morrison, *Research methods in education*. London: Routledge, 2018.
[34] K. Ofstedal and K. Dahlberg, "Collaboration in student teaching: Introducing the collaboration self-assessment tool," *Journal of Early Childhood Teacher Education*, vol. 30, no. 1, pp. 37–48, Feb. 2009, doi: 10.1080/10901020802668043.
[35] A. Bertucci, S. Conte, D. W. Johnson, and R. T. Johnson, "The impact of size of cooperative group on achievement, social support, and self-esteem," *Journal of General Psychology*, vol. 137, no. 3, pp. 256–272, Jun. 2010, doi: 10.1080/00221309.2010.484448.
[36] H. Pashler, M. McDaniel, D. Rohrer, and R. Bjork, "Learning Styles: Concepts and Evidence," *Psychological Science in the Public Interest*, vol. 9, no. 3, pp. 105–119, Dec. 2008, doi: 10.1111/j.1539-6053.2009.01038.x.
[37] C. Buchs, A. Dumesnil, J. Chanal, and F. Butera, "Dual effects of partner's competence: resource interdependence in cooperative learning at elementary school," *Education Sciences*, vol. 11, no. 5, p. 210, Apr. 2021, doi: 10.3390/educsci11050210.
[38] P. H. Hsieh and F. Dwyer, "The instructional effect of online reading strategies and learning styles on student academic achievement," *Educational Technology and Society*, vol. 12, no. 2, pp. 36–50, 2009.
[39] A. Abramczyk and S. Jurkowski, "Cooperative learning as an evidence-based teaching strategy: what teachers know, believe, and how they use it," *Journal of Education for Teaching*, vol. 46, no. 3, pp. 296–308, 2020, doi: 10.1080/02607476.2020.1733402.

BIOGRAPHIES OF AUTHORS

Ngan Hai My Le is a faculty member of the Faculty of Physics in Ho Chi Minh City University of Education (HCMUE). She is a teacher and researcher of science education. She earned her Ph.D. from the Faculty of Physics at Hanoi National University of Education, Vietnam. She has participated in some STEM education projects of HCMUE and the Ministry of Education and Training of Vietnam. Her research focuses on science education, STEM education, ICT in education. Currently, her research is directed toward the application of active learning methodologies, STEM education, and ICT in education to enhance student engagement and learning outcomes. She can be contacted at email: nganlhm@hcmue.edu.vn.

Anh Thi Kim Nguyen earned master from Graduate Institute Digital Learning and Education, National Taiwan University of Science and Technology, Keelung Rd, Da'an District, Taipei City, Taiwan. Her current research focuses on physics education, STEM education, collaborative learning, board game, and augmented reality. She aims to enhance student engagement and foster innovative learning experiences through her interdisciplinary approach. She can be contacted at email: anhntk.hcmue@gmail.com; m11211808@ms.ntust.edu.tw.