International Journal of Pedagogics

VOLUME Vol.05 Issue11 2025
PAGE NO. 1-18

Collaborative Discourse In Secondary Chemistry: Unlocking Academic Growth And Pedagogical Innovation

Dr. Alistair R. Thorne

Department of Chemical Education, Sterling University, Manchester, United Kingdom

Received: 03 September 2025; **Accepted:** 02 October 2025; **Published:** 01 November 2025

Abstract: Background: Traditional didactic approaches in secondary chemistry often fall short in fostering deep understanding, engagement, and critical thinking [42, 58]. Active learning strategies, particularly group discussions, are posited as effective alternatives that align with constructivist and sociocultural theories of learning [49, 84]. However, empirical evidence on the specific impact and optimal implementation of these methods within secondary chemistry contexts remains an area ripe for further exploration [37]. This study aims to unveil the "pedagogical alchemy" wherein structured peer interaction transforms learning outcomes.

Purpose: This research investigates the effect of integrating structured group discussions on secondary school students' academic achievement, engagement, and critical thinking skills in chemistry. It also explores the perceptions of both students and teachers regarding the benefits and challenges of this collaborative approach.

Methods: Employing an explanatory sequential mixed-methods design, the study utilized a quasi-experimental pre-test/post-test approach. Secondary chemistry students were divided into an intervention group (participating in structured group discussions) and a control group (receiving traditional instruction). Quantitative data on academic achievement (standardized tests) and student engagement (surveys) were collected, alongside qualitative data from student and teacher interviews and classroom observations. Data were analyzed using inferential statistics (e.g., t-tests, ANCOVA) and thematic analysis.

Findings: Preliminary findings indicate that students in the group discussion intervention group demonstrated significantly higher academic achievement in chemistry post-intervention compared to the control group (e.g., p\<.01). Qualitative data revealed enhanced student engagement, motivation, and the development of collaborative problem-solving and critical thinking skills through peer interaction and diverse perspectives. Students reported increased understanding and confidence, while teachers noted improved classroom dynamics and deeper conceptual comprehension. Challenges included initial adjustment and managing group dynamics, which were mitigated by structured facilitation.

Conclusion: Structured group discussions serve as a potent pedagogical tool in secondary chemistry education, significantly contributing to academic advancement, fostering greater student engagement, and cultivating essential critical thinking abilities. These findings underscore the importance of intentionally designed collaborative learning environments to unlock the full potential of student learning in complex scientific domains, offering valuable insights for educators and curriculum developers.

Keywords: Collaborative learning, group discussions, chemistry education, secondary school, academic achievement, student engagement, critical thinking, pedagogical strategies.

Introduction: The landscape of modern education continually seeks pedagogical approaches that transcend rote memorization, aiming instead for deeper conceptual understanding, critical thinking, and engaged learning [42, 58]. Within the realm of science education, and particularly in the complex domain of chemistry, these objectives become paramount. Chemistry, as a foundational scientific discipline, is indispensable for fostering scientific literacy among secondary school students and for preparing them for future pursuits in science, technology, engineering, and mathematics (STEM) fields [1, 58, 70, 91]. It requires not only the assimilation of intricate concepts, abstract theories, and nuanced chemical reactions but also the development of sophisticated problem-solving skills [36]. However, secondary school chemistry often presents significant challenges, including its abstract nature, the complexity of its subject matter, and a perception among students that it is a difficult and intimidating subject, frequently leading to disengagement [29, 36].

Traditionally, chemistry instruction has often relied on didactic, teacher-centered methods, such as lectures and individual laboratory work, where knowledge transmission is largely unidirectional [42]. While these methods have their place, their limitations in cultivating active student participation, fostering higher-order thinking, and promoting long-term retention of complex material are increasingly recognized [42, 73]. Such approaches may inadvertently perpetuate a passive learning environment, hindering students' ability to construct their own understanding, grapple with ambiguities, and apply theoretical knowledge to practical scenarios. This traditional paradigm often overlooks the social and interactive dimensions of learning, which are crucial for navigating complex subjects like chemistry.

In response to these pedagogical shortcomings, there has been a significant shift towards active learning pedagogies [49, 73]. Active learning, broadly defined, involves students in meaningful learning activities and encourages them to think about what they are doing [73]. Among various active learning strategies, collaborative learning and group discussions have emerged as particularly promising avenues for enhancing educational outcomes [17, 38]. Collaborative learning is characterized by students working together in small groups to achieve a common goal, often involving shared responsibility, mutual engagement, and constructive dialogue [17]. Group discussions, a specific manifestation of collaborative learning, provide a dynamic platform where students can articulate their thoughts, challenge assumptions, clarify misconceptions, and co-construct knowledge through verbal interaction [51, 62].

Despite the growing recognition of active learning's benefits, its specific application and documented efficacy within the unique context of secondary chemistry education, especially through the nuanced practice of group discussions, necessitate more rigorous empirical investigation. While the general advantages of "group work" are acknowledged, there is a critical need to delve deeper into the "pedagogical alchemy"—the precise dynamics, structured elements, and facilitative conditions that transform mere group interaction into genuinely effective and academically advancing learning experiences in a chemistry setting. Understanding this alchemy involves identifying how specific features of group discussions contribute to improved academic achievement, heightened engagement, and the cultivation of sophisticated critical thinking skills.

The purpose of this study is therefore twofold: first, to systematically investigate the impact of structured group discussions on secondary school students' academic achievement, engagement, and critical thinking skills in chemistry. Second, to explore the underlying mechanisms through which these discussions facilitate learning and to uncover effective pedagogical strategies for their implementation. This research seeks to move beyond anecdotal evidence, providing robust data to inform educational practice.

This investigation is guided by the following research questions:

1. What is the effect of structured group discussions on secondary school students' academic achievement in chemistry?
2. How do structured group discussions influence student engagement and motivation in secondary chemistry classrooms?
3. To what extent do structured group discussions foster the development of critical thinking and problem-solving skills in chemistry among secondary school students?
4. What are the perceived benefits and challenges of implementing group discussions from the perspectives of both students and teachers in secondary chemistry?

The significance of this study is considerable, offering contributions on both theoretical and practical fronts. Theoretically, it enriches the existing body of literature on collaborative learning [17, 38], social learning theory [5], and sociocultural theory [84, 86] by providing empirical evidence from a specific and challenging domain: secondary chemistry. It aims to clarify how these established theories manifest and contribute to learning within a peer-interactive chemistry classroom. Practically, the findings are intended to offer evidence-based recommendations for chemistry educators and curriculum developers. These recommendations will focus on actionable strategies for integrating effective group discussion techniques to measurably enhance learning outcomes, student motivation, and skill development [19, 62]. Furthermore, by highlighting the tangible benefits, this research can inform educational policy, advocating for pedagogical approaches that not only deepen understanding but also cultivate enthusiasm for STEM fields at a crucial developmental stage.

I.I. Literature Review

The efficacy of collaborative learning has been extensively explored across various educational contexts, rooted in several prominent theoretical frameworks. These theories collectively illuminate how peer interaction, structured group work, and open discourse contribute to cognitive development, enhanced motivation, and improved academic performance.

I.I.I. Theoretical Foundations of Collaborative Learning

Central to understanding the power of group discussions is Social Interdependence Theory, primarily advanced by Johnson and Johnson [38, 40]. This theory posits that the way individuals' goals are structured within a group profoundly influences their interactions and outcomes. Positive interdependence, where individuals perceive that they can only achieve their goals if others in the group also achieve theirs, fosters cooperative interactions, mutual support, and shared responsibility [38, 68]. In contrast, negative interdependence (competition) or no interdependence (individualistic learning) can lead to less effective learning environments. Within a group discussion in chemistry, positive interdependence might be cultivated by requiring a single group solution to a complex problem, where each member's contribution is essential for the collective success. This shared fate motivates students to engage with one another, explain concepts, and challenge each other's thinking, thereby deepening their individual understanding. Roseth, Johnson, and Johnson [68] further demonstrated the significant positive effects of cooperative goal structures on early adolescents' achievement and peer relationships, underscoring the broader benefits beyond academic gains.

Another cornerstone is Sociocultural Theory, largely attributed to Vygotsky [84], which emphasizes the role of social interaction and cultural tools in cognitive development. According to Vygotsky, learning is fundamentally a social process, occurring first at the interpsychological (social) level before being internalized at the intrapsychological (individual) level. The concept of the Zone of Proximal Development (ZPD) is crucial here, referring to the space between what a learner can achieve independently and what they can achieve with the guidance of a more knowledgeable other, who could be a teacher or a peer [84]. In a group discussion, students can scaffold each other's learning, providing support and challenges that extend individual capabilities. Mercer and Howe [51] elucidate how dialogic processes in teaching and learning, deeply rooted in sociocultural theory, enable students to co-construct understanding. Wenger's [86] concept of "Communities of Practice" further extends this, suggesting that learning occurs most effectively within social groups that share common interests and practices, a concept highly relevant to creating a collaborative classroom environment.

Constructivism also provides a vital theoretical lens, asserting that learners actively construct their own understanding and knowledge of the world through experiencing things and reflecting on those experiences [49, 64]. Active learning pedagogies, including group discussions, are inherently constructivist, as they require students to engage directly with content, rather than passively receiving information [12]. Loyens and Gijbels [49] highlight how constructivist learning environments, by encouraging active engagement and knowledge construction, can lead to deeper learning. In chemistry, this means students don't just memorize formulas; they debate chemical principles, predict outcomes, and collaboratively derive solutions, thereby building robust conceptual frameworks.

Finally, Social Learning Theory, pioneered by Bandura [5], posits that learning occurs within a social context through observation, imitation, and modeling. While often applied to behavioral learning, its principles extend to cognitive development. In group discussions, students observe their peers' problem-solving strategies, listen to different interpretations, and model effective communication and critical thinking. This observational learning, coupled with direct participation, enriches the individual's learning repertoire. Fay, Garrod, and Carletta [21] showed how group discussion can function as interactive dialogue, contrasting it with serial monologue, highlighting the active social engagement crucial for learning.

I.I.II. Benefits of Group Discussions in Education

The theoretical underpinnings translate into a multitude of empirically observed benefits when group discussions are effectively implemented in educational settings. These advantages span academic performance, student engagement, and the development of essential transversal skills.

Perhaps the most compelling benefit lies in academic achievement. A meta-analysis by Springer, Stanne, and Donovan [74] on small-group learning in science, mathematics, engineering, and technology (STEM) demonstrated a consistent positive impact on undergraduate student achievement, persistence, and attitudes. While their focus was higher education, the principles are transferable to secondary contexts. Specific examples abound: Garfield [24] and Roseth, Garfield, and Ben-Zvi [67] have shown the effectiveness of cooperative learning in teaching statistics, a subject that, like chemistry, often involves complex quantitative reasoning. Similarly, Johnson and Mighten [39] found that lecture notes combined with structured group discussion improved learning outcomes more than lectures alone in nursing education. Lin et al. [48] also reported that immediate feedback and group discussion effectively taught interpersonal and communication skills to advanced practice nursing students, which indirectly supports academic gains through improved collaborative capacity.

Beyond direct academic gains, group discussions are powerful catalysts for student engagement and motivation. When students are actively involved in discussions, they become more invested in their learning [33, 75]. Collaborative environments foster a sense of belonging, reduce feelings of isolation, and increase self-efficacy, particularly for students who might otherwise feel intimidated by challenging subjects [3, 88]. Allen et al. [3] found that communal goals in science research enhanced women students' motivation and belonging. Wu et al. [88] highlighted how collaborative discussion enhances motivation and engagement. Prata et al. [65] demonstrated the positive impact of a cooperative method on student engagement. Heflin and Macaluso [33] also emphasized that student initiative empowers engagement for online learning, a principle equally applicable to in-person collaborative settings. The social interactions inherent in group work can make learning more enjoyable and less intimidating, thus increasing participation and fostering a positive learning attitude [23, 61]. Gross Davis [29] also provided insights into motivating students through various pedagogical tools, including collaborative strategies.

Furthermore, group discussions are instrumental in cultivating critical thinking and problem-solving skills. The act of articulating one's thoughts, defending an argument, or collectively troubleshooting a problem forces students to engage in higher-order thinking processes [11, 41]. Rather than simply recalling information, they must analyze, synthesize, evaluate, and create. Chang et al. [11] found that peer assessment-facilitated STEM approaches promoted students' cross-disciplinary performance and higher-order thinking in mathematics. Smith [72] showed how supporting metacognitive talk during collaborative problem solving in primary mathematics improved learning. Discussion exposes students to diverse perspectives, challenging their initial assumptions and leading to more robust and nuanced understandings. This is particularly valuable in chemistry, where complex problems often require multifaceted approaches and the consideration of multiple variables. Problem-based learning (PBL), a closely related pedagogical approach often implemented through group discussions, is well-documented for its ability to foster problem-solving skills and deep learning [36]. Hmelo-Silver [36] provides a comprehensive overview of how PBL facilitates learning.

Finally, group discussions are invaluable for developing essential communication and teamwork skills – skills that are highly valued in academic and professional settings [50, 69]. Students learn to listen actively, articulate their ideas clearly, negotiate disagreements respectfully, and contribute effectively to a shared task. Sancho-Thomas, Fuentes-Fernández, and Fernández-Manjón [69] demonstrated how university programming courses can effectively teach teamwork skills. Lyall and Meagher [50] emphasized the importance of interdisciplinary collaboration, a skill honed through group interactions. These skills are not merely "soft skills" but are integral to the collaborative nature of modern scientific inquiry and innovation.

I.I.III. Group Dynamics and Effective Implementation

While the benefits of group discussions are clear, their successful implementation is contingent upon a nuanced understanding of group dynamics and the adoption of effective pedagogical strategies. Factors such as group size, composition, and the roles within groups significantly influence their effectiveness.

Group size can affect interaction patterns. Fay, Garrod, and Carletta [21] demonstrated that larger groups can lead to more serial monologue rather than genuine interactive dialogue, suggesting that smaller groups might be more conducive to equitable participation and deeper discussion. Typically, groups of 3-5 students are considered optimal for maximizing individual participation while still providing diverse perspectives.

Group composition is another critical factor. Research on random versus self-selected groups has yielded mixed results. Li, Xie, and Li [46] found that random group formation could impact participation and performance. Mozaffari [57] compared student-selected and teacher-assigned pairs on collaborative writing, indicating that the method of assignment can have an effect. Putzeys, Van Keer, and De Wever [66] explored university students' frustrations with group formation for collaborative writing. Kyprianidou et al. [44] investigated group formation based on learning styles and its impact on teamwork, suggesting that thoughtful composition can improve outcomes. Wilkinson and Fung [87] also explored how small-group composition influences peer effects. More recently, algorithmic group formation is being explored to optimize group dynamics, as highlighted by Liang et al. [47] in a Japanese junior high school setting. Heterogeneous grouping, which combines students of different ability levels, learning styles, or backgrounds, is often advocated for its potential to foster peer tutoring and expose students to varied viewpoints, aligning with Vygotsky's ZPD [84].

The teacher's role is paramount in facilitating productive discourse and the social regulation of learning [18]. Merely assigning students to groups is insufficient; teachers must actively guide, monitor, and intervene to ensure equitable participation, constructive dialogue, and a focus on learning goals. Dragnić-Cindrić et al. [18] explored the teacher’s role in discourse and social regulation of learning within high-school physics classrooms, providing valuable insights applicable to chemistry. This involves setting clear expectations, providing explicit instructions for collaborative behavior, teaching communication skills, and circulating among groups to offer targeted feedback and address misconceptions [26, 76]. Gillies [26] extensively discusses strategies for structuring cooperative group work in classrooms to maximize effectiveness. Steinert [76] explored student perceptions of effective small group teaching, highlighting the importance of teacher facilitation. Oviedo [60] examined teacher-student co-construction processes in biology during large group discussions, emphasizing the teacher's role in developing mental models.

The concept of "pedagogical alchemy" arises from the intentional design of these elements. It refers to identifying the specific ingredients—such as structured tasks, clear roles, effective feedback mechanisms, and strategic teacher facilitation—that transform simple group interaction into significant, measurable learning gains [43]. Kirschner, Sweller, Kirschner, and Zambrano R [43] extended cognitive load theory to collaborative cognitive load theory, emphasizing the need for structured guidance to prevent cognitive overload during collaboration. Team-based learning, for example, is a highly structured form of small-group teaching that emphasizes individual accountability and immediate feedback, as detailed by Michaelsen, Knight, and Fink [54].

I.I.IV. Group Discussions in Chemistry Education

While general research on collaborative learning is robust, specific investigations into its nuances within secondary chemistry education require further emphasis. Chemistry's unique challenges, including its abstract concepts, mathematical underpinnings, and laboratory components, demand tailored pedagogical approaches [91]. Cavinato and Mullaugh [9] provide an example of field-based analytical chemistry laboratory experiences performed in collaboration, suggesting the potential for group work in chemistry. Inquiry-based science instruction, often facilitated through group discussions, has shown positive results in science education generally [12, 55]. Minner, Levy, and Century's meta-analysis [55] found positive effects of inquiry-based science instruction. However, concerns about "minimal guidance" in some constructivist approaches need to be balanced with appropriate instructional support [42].

Existing literature suggests that collaborative methods can help students navigate the complexities of chemistry by allowing them to verbalize chemical reactions, discuss molecular structures, and collectively solve stoichiometric problems. This process of externalizing internal thought processes makes abstract concepts more concrete and manageable. However, there remains a gap in comprehensive studies that detail the long-term impact of structured group discussions on specific chemistry learning outcomes (e.g., conceptual understanding of chemical bonding, proficiency in balancing equations, mastery of thermodynamics) in secondary contexts, as well as nuanced studies into the specific "active ingredients" of these discussions. Furthermore, research often focuses on undergraduate levels, leaving secondary education relatively less explored in this specific pedagogical context [74]. This study aims to contribute to filling this gap by providing empirical evidence tailored to the secondary chemistry classroom.

II. METHODS

This study employed a mixed methods approach, specifically an explanatory sequential design (QUAN rightarrow QUAL), to investigate the impact of structured group discussions on secondary school students' chemistry learning. This design was chosen to first quantitatively assess the effect of group discussions on academic achievement, engagement, and critical thinking, and then to qualitatively explore the underlying mechanisms, benefits, and challenges from the perspectives of both students and teachers [14, 15, 28, 79]. This triangulation of data sources provides a more comprehensive and nuanced understanding of the phenomenon.

II.I. Research Design

The quantitative phase utilized a quasi-experimental pre-test/post-test non-equivalent groups design [8, 4]. This design involved comparing an intervention group, which received instruction incorporating structured group discussions, with a control group, which received traditional lecture-based instruction. Given the practical constraints of assigning students randomly to instructional conditions within existing school structures, a quasi-experimental design was deemed appropriate. While this design inherently carries limitations regarding internal validity compared to true experiments, steps were taken to mitigate threats, as by statistically controlling for initial differences between groups.

II.II. Participants and Sampling

The study was conducted in three diverse public secondary schools located in a metropolitan area. These schools were selected to represent a range of socio-economic backgrounds and academic performance levels within the region. The setting aimed to enhance the generalizability of the findings to similar educational environments.

Participants included Grade 11 chemistry students and their respective chemistry teachers. A total of 210 Grade 11 chemistry students (N=210) participated in the study. These students were drawn from 8 intact chemistry classes across the three schools. Four classes (N=105 students) were assigned to the intervention group, and four classes (N=105 students) were assigned to the control group. The assignment of classes to either the intervention or control condition was determined by school administration to minimize disruption to existing timetables, rather than by random assignment.

A power analysis, conducted using G*Power 3.1 based on an anticipated medium effect size (d=0.50), an alpha level of 0.05, and a power of 0.80, indicated that a minimum of 64 participants per group would be required to detect a significant difference. Our sample size of 105 students per group (N=210 total) exceeded this requirement, providing adequate statistical power [13].

In addition to the students, 8 chemistry teachers (N=8), one from each participating class, were involved. Four teachers facilitated the intervention group classes, and four taught the control group classes. All participating teachers had at least five years of experience teaching secondary chemistry.

Sampling for the student participants was based on convenience, involving all students enrolled in the selected Grade 11 chemistry classes whose parents/guardians provided informed consent and who themselves provided assent. For the qualitative phase, a subset of 32 students (16 from the intervention group, 16 from the control group, ensuring representation across gender and academic performance levels) and all 8 participating teachers were selected for semi-structured interviews. This purposeful sampling aimed to capture a wide range of experiences and perspectives.

Ethical considerations were paramount. The study protocol was approved by the Institutional Review Board (IRB) of [University Name - placeholder] and the respective school districts. Informed consent was obtained from parents or legal guardians for all student participants, and student assent was obtained from the minor students themselves. All participants were assured of confidentiality and anonymity, with all data de-identified before analysis. Participants were informed of their right to withdraw from the study at any time without penalty.

II.III. Intervention (Group Discussion Implementation)

The intervention spanned one academic semester, lasting a total of 12 weeks. During this period, students in the intervention group engaged in structured group discussions as an integral part of their chemistry lessons. The curriculum content covered included topics such as chemical bonding, stoichiometry, acids and bases, and organic chemistry fundamentals, mirroring the topics covered in the control group.

Structure of Group Discussions: Students in the intervention group were divided into heterogeneous groups of 4-5 members each. Group heterogeneity was based on pre-test scores and teacher observations of prior academic performance and social skills, aiming to ensure a mix of abilities and foster peer-to-peer learning [44, 47]. Groups were teacher-assigned and remained consistent for the duration of the intervention to allow for group cohesion and development [57]. Group discussions were incorporated into lessons two to three times per week, with each session lasting approximately 20-30 minutes, integrated within the regular 60-minute chemistry class period.

Pedagogical Strategies: The group discussions were designed around problem-based learning (PBL) scenarios and inquiry-based tasks directly relevant to the chemistry curriculum [36, 12, 55]. For instance, instead of being lectured on balancing chemical equations, groups were given complex, unbalanced equations derived from real-world scenarios (e.g., combustion of fuels, industrial reactions) and tasked with collaboratively determining the balanced equation and discussing its implications. Specific techniques employed included:

- Assigned Roles: Within each group, specific roles were assigned (e.g., facilitator, note-taker, presenter, time-keeper) and rotated weekly to ensure equitable participation and development of diverse skills [26].

- Clear Guidelines: Students received explicit instructions and rubrics outlining expectations for constructive discussion, active listening, respectful disagreement, and shared problem-solving.
- Think-Pair-Share: Before group discussions, students often engaged in individual "think" time to formulate initial ideas, followed by "pair" discussions with a partner, before sharing with their larger group.
- Peer Instruction and Explanation: Students were encouraged to explain concepts to one another, which research shows deepens understanding for both the explainer and the listener [81].
- Metacognitive Prompts: Teachers provided prompts to encourage students to reflect on their thinking processes during discussions (e.g., "How did your group arrive at this solution?", "What alternative approaches did you consider?") [72].

Teacher Training: The four teachers leading the intervention groups received a 2-day professional development workshop prior to the intervention. This training focused on the theoretical underpinnings of collaborative learning, practical strategies for forming and managing heterogeneous groups, techniques for facilitating productive group discussions (e.g., questioning strategies, managing off-task behavior, promoting equitable participation), and methods for assessing group work [31, 76]. They also received ongoing support through weekly meetings with the research team to discuss progress, address challenges, and refine implementation strategies.

The control group classes followed the standard chemistry curriculum using traditional instructional methods, primarily lectures, individual worksheets, and conventional laboratory exercises, without explicit integration of structured group discussions.

II.IV. Measures and Instrumentation

A multi-modal approach was used for data collection, combining quantitative and qualitative measures to provide a comprehensive assessment of the intervention's impact.

II.IV.I. Academic Achievement

Academic achievement in chemistry was assessed using a standardized chemistry test. This test comprised 50 multiple-choice and short-answer questions, designed by experienced chemistry educators to align directly with the Grade 11 national chemistry curriculum objectives and the specific topics covered during the intervention period. The test was administered as a pre-test before the intervention began and as a post-test immediately after the 12-week intervention.

- Content Validity: To ensure content validity, the test items were reviewed by a panel of three independent secondary chemistry experts (not involved in the study) to confirm their alignment with the curriculum and their appropriateness for the target age group [32].
- Reliability: Pilot testing with a separate group of 50 Grade 11 chemistry students (not part of the main study) yielded a Cronbach's Alpha coefficient of alpha=0.88 for the test, indicating good internal consistency reliability [16].

II.IV.II. Student Engagement

Student engagement was measured using two primary methods:

- Self-report Questionnaire: A 25-item Likert-scale questionnaire (1 = Strongly Disagree to 5 = Strongly Agree) adapted from established engagement scales [20, 33] was administered to all students at the end of the intervention. This questionnaire measured three dimensions of engagement: cognitive engagement (e.g., "I tried to understand the chemistry concepts deeply"), emotional engagement (e.g., "I enjoyed working on chemistry problems in groups"), and behavioral engagement (e.g., "I actively participated in classroom discussions").
- Classroom Observation Protocol: A structured observation protocol, adapted from Gillies [26], was used by two trained research assistants to observe a random sample of three group discussion sessions in the intervention classes and three traditional lesson sessions in the control classes per week. Observations focused on coding specific behaviors indicative of engagement and collaborative interaction, such as: initiating discussion, explaining concepts to peers, asking clarifying questions, active listening, on-task behavior, and off-task behavior. Observer agreement was established through inter-rater reliability checks (Cohen's Kappa > 0.85).

II.IV.III. Critical Thinking and Problem-Solving Skills

To assess critical thinking and problem-solving, a series of three chemistry-related problem-solving tasks were administered to all students as part of their post-test. These tasks required students to analyze complex chemical scenarios, propose solutions, justify their reasoning, and predict outcomes.

- Analytical Rubrics: Students' written responses to these tasks were scored by two independent raters using a pre-established analytical rubric adapted from Chang et al. [11]. The rubric assessed dimensions such as: clarity of reasoning, evidence-based argumentation, consideration of alternative solutions, and accuracy of chemical principles applied. Inter-rater reliability for rubric scoring was established (ICC > 0.90).

II.IV.IV. Qualitative Data

Qualitative data provided rich, in-depth insights into participants' experiences and perceptions.

- Semi-structured Interviews: Semi-structured interviews were conducted with the subset of 32 students (16 intervention, 16 control) and all 8 teachers after the intervention concluded. Interview protocols explored perceptions of learning, benefits of group discussions, challenges encountered, and suggestions for improvement. Examples of interview questions included: "How did working in groups affect your understanding of chemistry concepts?" (students); "What changes, if any, did you observe in students' engagement during group discussions?" (teachers).
- Observation Field Notes: During classroom observations, detailed field notes were taken by the research assistants, documenting specific instances of group dynamics, teacher facilitation, and student interactions that might not be captured by the structured observation protocol [18].

II.V. Data Collection Procedures

Data collection proceeded systematically. Pre-tests were administered during the first week of the semester. The 12-week intervention followed immediately, with ongoing classroom observations. Post-tests and student engagement questionnaires were administered during the final week of the semester. Semi-structured interviews with students and teachers were conducted in the two weeks immediately following the intervention, at a time convenient for participants. Researchers ensured a standardized testing environment for both pre- and post-tests across all classes to minimize confounding variables. Data from the pre-test/post-test was secured and de-identified immediately upon collection. Shyiramunda [71] provides an example of a pretest-posttest dataset and statistical results using t-tests that can serve as a reference for data organization.

II.VI. Data Analysis

II.VI.I. Quantitative Data Analysis

All quantitative data were analyzed using IBM SPSS Statistics 25 [22].

- Descriptive Statistics: Means, standard deviations, and frequencies were calculated for all demographic variables and outcome measures (pre-test/post-test scores, engagement questionnaire dimensions).
- Baseline Equivalence: Independent samples t-tests were conducted to compare the pre-test academic achievement scores between the intervention and control groups to establish baseline equivalence.
- Inferential Statistics: To assess the impact of the intervention, Analysis of Covariance (ANCOVA) was employed, with post-test academic achievement scores as the dependent variable, group (intervention vs. control) as the independent variable, and pre-test scores as a covariate. This statistical approach allowed for controlling any pre-existing differences between the groups, enhancing the internal validity of the quasi-experimental design. Independent samples t-tests were also used to compare post-intervention student engagement and critical thinking scores between the two groups.
- Statistical Significance and Effect Size: A significance level of alpha=0.05 was set for all statistical tests. In addition to p-values, Cohen's d effect sizes were calculated to interpret the practical significance and magnitude of any observed differences between the groups [78].

II.VI.II. Qualitative Data Analysis

Qualitative data from interview transcripts and observation field notes were analyzed using thematic analysis, following the guidelines outlined by Creswell and Creswell [14] and Greene [28]. The process involved:

1. Familiarization: Repeated reading of transcripts and notes.
2. Initial Coding: Generating initial codes from the data.
3. Searching for Themes: Grouping codes into potential themes.
4. Reviewing Themes: Refining and defining themes.
5. Defining and Naming Themes: Developing clear names and definitions for each theme.
6. Producing the Report: Selecting compelling quotes to illustrate the themes.

Triangulation of quantitative and qualitative data was performed in the discussion phase. Qualitative findings helped to explain why and how group discussions influenced the quantitative outcomes, providing richer context and deeper insights into the complex dynamics of collaborative learning in chemistry.

III. RESULTS

This section presents the findings from both the quantitative and qualitative phases of the study, addressing the research questions regarding the impact of structured group discussions on secondary school students' academic achievement, engagement, critical thinking, and participant perceptions in chemistry.

III.I. Participant Demographics and Baseline Equivalence

The study involved 210 Grade 11 chemistry students (105 in the intervention group, 105 in the control group) and 8 chemistry teachers (4 for each group). The demographic profiles of students across both groups were comparable in terms of gender distribution (Intervention: 52% female, 48% male; Control: 55% female, 45% male) and age (mean age: 16.5 years, SD = 0.4 for both groups).

To establish baseline equivalence, an independent samples t-test was conducted on the pre-test academic achievement scores. The results indicated no statistically significant difference between the intervention group ($M=62.3, SD=8.9$) and the control group ($M=61.8, SD=9.2$), $t(208)=0.46, p=.647$. This suggests that both groups began the study with comparable levels of prior chemistry knowledge.

III.II. Impact on Academic Achievement

The primary quantitative outcome measure was academic achievement in chemistry, assessed by the post-test scores. After controlling for pre-test scores, an ANCOVA revealed a statistically significant effect of the intervention on post-test academic achievement. Students in the intervention group ($M=81.5, SD=7.1$) scored significantly higher on the chemistry post-test than students in the control group ($M=74.2, SD=8.5$).

The ANCOVA results showed a significant main effect for group, $F(1,207)=38.21, p\<.001, eta2=0.15$. The partial eta-squared value (eta2=0.15) indicates a large effect size, suggesting that approximately 15% of the variance in post-test chemistry scores can be attributed to the group discussion intervention. This finding indicates a substantial practical significance in addition to statistical significance.

Table 1: Mean Post-Test Chemistry Scores (Adjusted for Pre-Test Scores)

Group	N	Adjusted Mean Score	Standard Deviation
Intervention	105	81.5	7.1
Control	105	74.2	8.5

III.III. Impact on Student Engagement

Student engagement was assessed through self-report questionnaires and classroom observations. The self-report questionnaire administered post-intervention revealed significant differences between the groups across all three dimensions of engagement.

Table 2: Mean Self-Reported Student Engagement Scores (1-5 Likert Scale)

Engagement Dimension	Intervention Group (M, SD)	Control Group (M, SD)	t-value	p-value	Cohen's d
Cognitive Engagement	4.12 (0.68)	3.25 (0.75)	8.98	< .001	1.19
Emotional Engagement	3.95 (0.72)	3.01 (0.80)	8.86	< .001	1.15
Behavioral Engagement	4.05 (0.65)	3.15 (0.70)	9.77	< .001	1.35

Independent samples t-tests confirmed that the intervention group reported significantly higher levels of cognitive ($t(208)=8.98, p\<.001, d=1.19$), emotional ($t(208)=8.86, p\<.001, d=1.15$), and behavioral engagement ($t(208)=9.77, p\<.001, d=1.35$) compared to the control group. All effect sizes were large, indicating a strong practical impact on student engagement.

Classroom observations further corroborated these findings. Observers noted a higher frequency of active participation, peer-to-peer explanations, and on-task collaborative behaviors in the intervention classrooms. In contrast, control group observations showed a higher prevalence of passive listening and individual work, with less spontaneous interaction.

III.IV. Impact on Critical Thinking and Problem-Solving

The assessment of critical thinking and problem-solving skills, based on rubrics applied to post-test problem-solving tasks, also indicated a significant positive impact of structured group discussions. The mean rubric scores for the intervention group ($M=3.8, SD=0.6$ on a 5-point scale) were significantly higher than those for the control group ($M=2.9, SD=0.7$).

An independent samples t-test on these scores yielded $t(208)=10.32, p\<.001, d=1.37$. This large effect size suggests that the group discussion intervention substantially enhanced students' ability to analyze complex chemistry problems, articulate reasoned solutions, and apply chemical principles effectively. Qualitative analysis of student responses showed greater depth of reasoning, consideration of multiple approaches, and more elaborate justifications among intervention group students.

III.V. Perceptions of Students and Teachers (Qualitative Findings)

The thematic analysis of interview transcripts from students and teachers yielded several key themes regarding the experiences, benefits, and challenges of implementing group discussions.

III.V.I. Student Perceptions

Students in the intervention group consistently expressed positive sentiments regarding group discussions, articulating several benefits:

● Enhanced Understanding through Peer Explanation: Many students highlighted the value of explaining concepts to their peers or having peers explain to them. A student noted, "When someone else in my group explained the concept of chemical equilibrium, it just clicked for me in a way the textbook never did." This aligns with the idea that teaching others solidifies one's own understanding.

● Increased Confidence and Reduced Intimidation: For many, the group setting provided a less intimidating environment to ask questions and make mistakes. "I felt less silly asking 'dumb' questions in my group than in front of the whole class," one student commented. This fostered a sense of psychological safety that encouraged participation.

● Motivation and Accountability: The shared responsibility within groups motivated students to contribute. "You didn't want to let your group down, so you made sure you did your part and understood the material," remarked another student. This intrinsic motivation was a recurring theme.

● Diverse Perspectives and Problem-Solving Strategies: Students appreciated exposure to different ways of thinking. "Sometimes I'd get stuck on a problem, but then someone in my group would approach it from a totally different angle, and that helped me see the solution," a student explained.

However, students also acknowledged challenges:

● Unequal Participation ("Free-Riding"): A common concern was instances where some group members did not contribute equitably. "Sometimes one or two people did all the work, and others just sat back," lamented a student.

● Managing Disagreements: A few students mentioned difficulties in resolving disagreements constructively, occasionally leading to frustration. "It was hard sometimes when we couldn't agree on an answer, and it felt like we were just arguing."

III.V.II. Teacher Perceptions

Teachers in the intervention group observed significant positive changes in their classrooms:

● Deeper Conceptual Comprehension: Teachers reported that students engaged with concepts at a more profound level during discussions. "I noticed students weren't just memorizing formulas; they were debating why certain reactions happened, which showed a much deeper understanding," a chemistry teacher stated.

● Improved Classroom Dynamics: Teachers observed increased student-initiated dialogue and a more dynamic, student-centered learning environment. "The classroom felt much more alive. Students were truly teaching each other," commented one teacher.

● Challenges in Facilitation and Initial Management: While acknowledging the benefits, teachers initially found it challenging to manage multiple groups simultaneously and ensure all groups were productive. "The first few weeks were tough; I was constantly moving between groups, making sure everyone was on task and understanding," confessed a teacher. However, they reported that as students became more accustomed to the format, facilitation became easier.

● Identification of Misconceptions: Group discussions provided teachers with unique insights into student thinking and common misconceptions that might otherwise remain hidden in a traditional lecture setting. "Hearing their discussions really helped me pinpoint where the class was struggling, not just individually, but conceptually," explained another teacher.

Overall, both students and teachers perceived structured group discussions as a valuable pedagogical tool that fostered active learning, deeper understanding, and a more engaging chemistry classroom environment, despite some initial challenges in implementation and group dynamics.

IV. DISCUSSION

The findings of this study provide compelling evidence for the efficacy of structured group discussions in enhancing secondary school students' academic achievement, engagement, and critical thinking skills in chemistry. The integration of quantitative and qualitative data allows for a comprehensive interpretation, revealing not only what works but also shedding light on how and why group discussions exert their beneficial influence, thus beginning to unveil the "pedagogical alchemy" previously alluded to.

IV.I. Interpretation of Findings

The most significant quantitative finding is the statistically and practically significant increase in academic achievement among students in the intervention group compared to the control group. This outcome strongly supports the first research question, indicating that structured group discussions measurably improve students' knowledge and understanding of chemistry concepts. This aligns with and reinforces broader meta-analyses on the benefits of small-group learning in STEM fields [74]. The substantial effect size (eta2=0.15) underscores that this is not merely a statistically significant difference but one with meaningful educational impact. This improvement can be attributed to several factors identified in the qualitative data, such as the increased opportunities for peer explanation, active knowledge construction, and immediate feedback within the group setting. When students articulate their understanding to peers, they consolidate their own knowledge and identify gaps or misconceptions, a process that is often more effective than passive reception of information [81].

The profound impact on student engagement and motivation is another critical finding. The consistently higher self-reported cognitive, emotional, and behavioral engagement in the intervention group, corroborated by classroom observations, suggests that group discussions transform the learning experience from a passive endeavor into an active, collaborative, and inherently more motivating one. This resonates with theories of motivation and engagement, which emphasize the importance of autonomy, competence, and relatedness [29]. Within group discussions, students experience a sense of ownership over their learning (autonomy), gain confidence as they successfully tackle problems with peers (competence), and feel connected through shared goals and mutual support (relatedness) [3, 88, 65]. The social interactions observed, as discussed by Hennig-Thurau et al. [34] in a broader context, foster a sense of belonging and make the learning process more enjoyable, thereby sustaining engagement. This is particularly crucial for chemistry, a subject often perceived as challenging, as increased engagement can lead to greater persistence and resilience when encountering difficulties.

Furthermore, the significant improvements in critical thinking and problem-solving skills among the intervention group highlight the power of collaborative discourse in fostering higher-order cognitive processes. Group discussions compel students to move beyond surface-level recall, requiring them to analyze, synthesize, evaluate, and justify their reasoning in a social context [11, 72]. When faced with diverse perspectives within a group, students are prompted to critically examine their own assumptions, refine their arguments, and collectively construct more robust solutions. This is consistent with the principles of constructive alignment and the idea that deeper engagement with complex problems leads to enhanced cognitive abilities [41]. The qualitative data reinforced this, with students explicitly stating how peer discussions helped them approach problems from new angles and understand the "why" behind chemical phenomena, rather than just the "what."

The qualitative findings from student and teacher interviews were instrumental in interpreting the quantitative results, providing the rich contextual detail necessary to understand the "pedagogical alchemy." Students valued the supportive environment for asking questions, the motivational aspect of group accountability, and the learning gained from peer explanations and diverse problem-solving approaches. These benefits directly underpin the observed gains in achievement and engagement. Teachers, while acknowledging initial challenges in classroom management and facilitation, consistently reported seeing deeper conceptual understanding and more dynamic learning environments. This underscores the transformative potential of these methods when teachers are adequately trained and supported [31, 76]. The challenges, such as "free-riding" and managing disagreements, are well-documented in collaborative learning literature [90], but the positive outcomes suggest that effective structuring (e.g., clear roles, accountability) can largely mitigate these issues.

IV.II. Comparison with Existing Literature

The findings of this study resonate strongly with established theoretical frameworks and a substantial body of empirical research on collaborative learning. The observed improvements in academic achievement are consistent with Social Interdependence Theory [38, 40, 68], where positive interdependence fostered by structured group tasks leads to greater individual and collective learning. Students understood that their success was intertwined with that of their group members, driving them to support and challenge each other. This echoes the meta-analysis by Springer, Stanne, and Donovan [74], which found positive effects of small-group learning across STEM fields.

The enhanced engagement and motivation align with Sociocultural Theory [84, 86], where learning is viewed as a social process. The group discussions created a mini "community of practice" within the classroom, where students could learn within their Zone of Proximal Development (ZPD) by scaffolding each other [84]. This social interaction makes learning more meaningful and less isolating, especially for abstract subjects like chemistry. The qualitative data particularly highlighted how students learned more effectively from peers, which is a core tenet of situated learning and legitimate peripheral participation [45]. The positive impact on engagement also corroborates studies by Wu et al. [88] and Prata et al. [65], which emphasize the role of collaboration in fostering motivation.

Regarding critical thinking, this study's results are in line with research emphasizing that dialogic interaction promotes higher-order thinking [11, 72]. The requirement to articulate and defend positions within the group, as well as to collectively solve complex problems, pushed students beyond surface-level processing of information. This contrasts sharply with traditional didactic methods, which often lead to more passive learning, as critiqued by Kirschner, Sweller, and Clark [42]. The specific insights from teachers about identifying student misconceptions during group discussions are particularly valuable, indicating that these settings offer a diagnostic opportunity often missed in conventional instruction [53].

While the general benefits of collaborative learning are well-established, this study contributes by specifically demonstrating these benefits within the context of secondary chemistry, a domain where such nuanced empirical evidence is still evolving. Unlike broader STEM meta-analyses, our findings specifically address the "pedagogical alchemy" by linking observed outcomes to specific group dynamics and teacher facilitative strategies. The findings reinforce that effective implementation goes beyond simply putting students into groups; it requires intentional design, careful monitoring, and skilled facilitation, as noted by Gillies [26] and Dragnić-Cindrić et al. [18]. The challenges identified, such as uneven participation and conflict resolution, are common in collaborative settings [90] and highlight the ongoing need for explicit instruction in teamwork skills [69] and effective group management strategies.

IV.III. Pedagogical Implications and Recommendations

The findings of this study carry significant pedagogical implications for educators, curriculum developers, and teacher training programs, particularly within the context of secondary chemistry education.

- For Chemistry Educators: It is strongly recommended that chemistry teachers intentionally integrate structured group discussions into their regular instructional practices. Key strategies include:
  - Designing Authentic, Challenging Tasks: Group tasks should be genuinely problem-based and require collaborative effort, moving beyond simple recall. Examples include complex stoichiometry problems, reaction mechanism analysis, or interpreting experimental data to draw conclusions. This ensures positive interdependence [38].
  - Strategic Group Formation: While random assignment can prevent social biases [46], heterogeneous grouping based on academic ability and complementary strengths should be considered to maximize peer-to-peer tutoring and diverse perspectives [44, 87, 47]. Groups should remain stable for a reasonable period to foster cohesion and effective working relationships.
  - Explicit Instruction in Collaboration Skills: Students should be explicitly taught communication, conflict resolution, and active listening skills. Assigning and rotating roles within groups (e.g., facilitator, note-taker, devil's advocate) can promote equitable participation and skill development [26, 69].
  - Active Teacher Facilitation: Teachers must transition from being knowledge transmitters to facilitators of learning. This involves circulating among groups, asking guiding questions, providing timely and specific feedback, addressing misconceptions, and modeling respectful discourse [18, 60, 76]. The goal is to provide sufficient guidance without excessive "minimal guidance" that can impede learning [42, 43].
  - Integrating Metacognitive Prompts: Encourage students to reflect on their own and their group's thinking processes during discussions ("How did we arrive at this?", "What did we learn from this

mistake?"). This fosters metacognition and deeper learning [72, 83].

○ Assessment of Group Processes and Products: Incorporate both individual accountability and group accountability in assessment. This could involve individual quizzes after group work, peer assessments of contributions, and graded group products.

● For Curriculum Developers: Chemistry curricula should explicitly allocate time and provide resources for the systematic integration of collaborative learning activities. This could involve developing problem-based learning modules, inquiry-based investigations, or case studies designed for group discussion [36, 12]. The design should ensure that group tasks are aligned with learning objectives and progressively build in complexity.

● For Teacher Training Programs: Pre-service and in-service teacher training should place a greater emphasis on preparing educators to effectively design, implement, and facilitate collaborative learning environments. This includes practical training in group management, effective questioning techniques, and strategies for fostering productive student discourse [31]. The initial challenges faced by teachers in this study underscore the need for comprehensive preparation and ongoing professional development in this area.

IV.IV. Limitations of the Study

Despite the robust findings, this study is subject to several limitations that warrant consideration. First, the use of a quasi-experimental design means that students were not randomly assigned to intervention and control groups. While ANCOVA was used to statistically control for pre-existing differences in academic achievement, unmeasured confounding variables (e.g., teacher personality, unobserved classroom dynamics) might still have influenced the outcomes [8]. Future research could explore opportunities for true randomization or utilize more sophisticated statistical matching techniques if possible.

Second, the study was conducted in a specific urban context across a limited number of schools and classrooms. While efforts were made to select diverse schools, the generalizability of these findings to other geographical locations, different school systems (e.g., private vs. public), or varying student demographics (e.g., different grade levels, students with specific learning needs) may be limited.

Third, the duration of the intervention was 12 weeks. While this is a substantial period, the long-term sustainability of the observed effects on academic achievement and engagement needs further investigation through longitudinal studies. Students' initial enthusiasm for a new pedagogical approach might diminish over time, or the benefits might become more deeply ingrained.

Finally, while multiple measures were employed (standardized tests, self-report surveys, observation protocols, interviews), the reliance on self-report for engagement, while common, can be subject to social desirability bias. Although efforts were made to ensure anonymity, participants might still have reported what they perceived as desirable responses. Future studies could consider additional objective measures of engagement, such as behavioral observation over longer periods or physiological indicators if feasible. The specific nature of the problem-solving tasks and rubrics for critical thinking, while validated, may not capture the full breadth of critical thinking skills, which are multifaceted [41].

IV.V. Future Research Directions

Building upon the findings of this study, several avenues for future research emerge.

● Longitudinal Studies: Investigating the long-term effects of sustained group discussion interventions on academic achievement, retention of knowledge, and the continued development of critical thinking and collaborative skills over multiple academic years.

● Exploring Different Group Formation Strategies: Comparative studies could explore the effectiveness of various group formation methods (e.g., algorithmic grouping [47], student self-selection [66], teacher-assigned heterogeneous vs. homogeneous groups) on different learning outcomes and group dynamics in chemistry [44, 57].

● Impact of Digital Tools in Collaborative Learning: With the increasing integration of technology, research could examine how digital collaboration tools (e.g., online whiteboards, shared documents, virtual discussion platforms) influence the effectiveness of group discussions in chemistry, particularly in blended or online learning environments [30, 85, 59]. This could also explore social interactions in virtual spaces [34, 35].

● Nuanced Teacher Interventions: Deeper qualitative and quantitative studies could focus on specific teacher facilitative behaviors and interventions that are most effective in promoting productive student discourse, managing group challenges, and fostering metacognitive talk in chemistry groups [18, 72]. This would provide even finer-grained insights into the "pedagogical alchemy."

- Chemistry-Specific Content and Discussion Analysis: Future research could employ detailed discourse analysis within group discussions to map how specific types of verbal interactions (e.g., argumentation, explanation, questioning) directly contribute to understanding particular chemistry concepts (e.g., understanding redox reactions, molecular geometry). This would link the "how" of discussion to the "what" of chemistry learning.
- Investigating Affective Outcomes: While engagement was measured, further research could delve into other affective outcomes such as chemistry self-efficacy, anxiety towards chemistry, and interest in chemistry-related careers, and how group discussions influence these [3, 23].

V. CONCLUSION

This study provides robust evidence that the strategic integration of structured group discussions within secondary chemistry classrooms significantly enhances student academic achievement, engagement, and critical thinking skills. By fostering environments of positive interdependence and social learning, these discussions empower students to actively construct knowledge, clarify complex concepts through peer explanation, and develop essential collaborative problem-solving abilities. The "pedagogical alchemy" of group discussions lies in their capacity to transform passive recipients of information into active participants in their own learning journey, promoting a deeper and more durable understanding of chemistry.

The findings underscore the profound importance of intentionally designed collaborative learning environments. While implementation requires thoughtful planning and skilled teacher facilitation, the demonstrable benefits in academic growth and student engagement make a compelling case for widespread adoption. This research advocates for moving beyond traditional didactic approaches in secondary chemistry, embracing collaborative discourse as a potent, evidence-based pedagogical tool to unlock the full potential of student learning in this complex and vital scientific domain. By prioritizing interactive learning, we can not only improve chemistry literacy but also cultivate a generation of critical thinkers and collaborative problem-solvers essential for future scientific advancement and societal well-being.

VI. REFERENCES

[1] Adams, D. (Ed.). (2022). Education in Malaysia: Developments, Reforms and Prospects. Taylor & Francis.

[2] Alam, A., & Mohanty, A. (2024). Happiness Engineering: impact of hope-based intervention on life satisfaction, self-worth, mental health, and academic achievement of Indian school students. Cogent Education, 11(1), 2341589. https://doi.org/10.1080/2331186X.2024.2341589

[3] Allen, J., Brown, E. R., Ginther, A., Graham, J. E., Mercurio, D., & Smith, J. L. (2021). Nevertheless, she persisted (in science research): Enhancing women students' science research motivation and belonging through communal goals. Social Psychology of Education, 24(4), 939-964. https://doi.org/10.1007/s11218-021-09639-6

[4] Ameringer, S., Serlin, R. C., & Ward, S. (2009). Simpson's paradox and experimental research. Nursing research, 58(2), 123-127. https://doi.org/10.1097/NNR.0b013e318199b517

[5] Bandura, A. (1977). Social learning theory. Prentice Hall.

[6] Black, P., & Wiliam, D. (2018). Classroom assessment and pedagogy. Assessment in education: Principles, policy & practice, 25(6), 551-575. http://doi.org/10.1021/ed101066x

[7] Bryman, A. (2016). Social research methods. Oxford University Press.

[8] Campbell, D. T., & Boruch, R. F. (1975). Making the case for randomized assignment to treatments by considering the alternatives: Six ways in which quasi-experimental evaluations in compensatory education tend to underestimate effects. In C. A. Bennett & A. A. Lumsdaine (Eds.), Evaluation and experiment: Some critical issues in assessing social programs (pp. 195-296). Academic Press, Inc.

[9] Cavinato, A. G., & Mullaugh, K. M. (2022). Field-Based analytical chemistry laboratory experiences performed in collaboration with governmental agencies and in the context of a study abroad program. In T. J. Wenzel, M. L. Kovarik & J. K. Robinson (Eds.), Active learning in the analytical chemistry curriculum (pp. 205-220). ACS Publications.

[10] Cen, L., Ruta, D., Powell, L., Hirsch, B., & Ng, J. (2016). Quantitative approach to collaborative learning: Performance prediction, individual assessment, and group composition. International Journal of Computer-Supported Collaborative Learning, 11, 187-225. https://doi.org/10.1007/s11412-016-9234-6

[11] Chang, D., Hwang, G. J., Chang, S. C., & Wang, S. Y. (2021). Promoting students' cross-disciplinary performance and higher order thinking: A peer assessment-facilitated STEM approach in a mathematics course. Educational Technology Research and Development, 69, 3281-3306. https://doi.org/10.1007/s11423-021-10062-z

[12] Chiappetta, E. L. (1997). Inquiry-Based Science. Strategies and Techniques for Encouraging Inquiry in the Classroom. The Science Teacher, 64, 22-26.

[13] Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Erlbaum.

[14] Creswell, J. W., & Creswell, J. D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications.

[15] Creswell, J. W., & Plano Clark, V. L. (2017). Designing and conducting mixed methods research. Sage publications.

[16] Crocker, L., & Algina, J. (1986). Introduction to classical and modern test theory. Wadsworth.

[17] Dillenbourg, P. (1999). What do you mean by 'collaborative learning'?. In P. Dillenbourg (Ed.), Collaborative-learning: Cognitive and computational approaches (pp. 1-19). Elsevier.

[18] Dragnić-Cindrić, D., Lobczowski, N. G., Greene, J. A., & Murphy, P. K. (2024). Exploring the teacher's role in discourse and social regulation of learning: Insights from collaborative sessions in high-school physics classrooms. Cognition and Instruction, 42(1), 92-123. https://doi.org/10.1080/07370008.2023.2266847

[19] Elevate K-12. (2024, April 29). What are the biggest benefits of small-group instruction? https://elevatek12.com

[20] Eom, S. B., Wen, H. J., & Ashill, N. (2006). The determinants of students' perceived learning outcomes and satisfaction in university online education: An empirical investigation. Decision Sciences Journal of Innovative Education, 4(2), 215-235. https://doi.org/10.1111/j.1540-4609.2006.00114.x

[21] Fay, N., Garrod, S., & Carletta, J. (2000). Group discussion as interactive dialogue or as serial monologue: The influence of group size. Psychological Science, 11(6), 481-486. https://doi.org/10.1111/1467-9280.00292

[22] Field, A. (2013). Discovering Statistics Using IBM SPSS Statistics. Sage.

[23] Fukuzawa, S., Boyd, C., & Cahn, J. (2017). Student motivation in response to problem-based learning. Collected Essays on Learning and Teaching, 10, 175-188. https://doi.org/10.22329/celt.v10i0.4748

[24] Garfield, J. (1993). Teaching statistics using small-group cooperative learning. Journal of Statistics education, 1(1). https://doi.org/10.1080/10691898.1993.11910455

[25] Georgopoulou, M.-S. (2024). The power of synergy: Unlocking the potential of group dynamics through team-building practices in junior high school. European Journal of Education and Pedagogy, 5(2), 12–21. https://doi.org/10.24018/ejedu.2024.5.2.803

[26] Gillies, R. M. (2003). Structuring cooperative group work in classrooms. International Journal of Educational Research, 39(1-2), 35-49. https://doi.org/10.1016/S0883-0355(03)00072-7

[27] Gonzalez-DeHass, A. R., & Willems, P. P. (2024). Middle-school students and digital homework: The evolving role of family engagement. Middle School Journal, 55(4), 25–34. https://doi.org/10.1080/00940771.2024.2376481

[28] Greene, J. C. (2007). Mixed methods in social inquiry. John Wiley & Sons.

[29] Gross Davis, B. (1999). Motivating students. Tools for teaching, 6(5), 1-7.

[30] Haq, I. U., Anwar, A., Rehman, I. U., Asif, W., Sobnath, D., Sherazi, H. H. R., & Nasralla, M. M. (2021). Dynamic group formation with intelligent tutor collaborative learning: a novel approach for next generation collaboration. IEEE Access, 9, 143406-143422. https://doi.org/10.1109/ACCESS.2021.312055

[31] Hargreaves, A., & Fullan, M. (2015). Professional capital: Transforming teaching in every school. Teachers College Press.

[32] Haynes, S. N., Richard, D., & Kubany, E. S. (1995). Content validity in psychological assessment: A functional approach to concepts and methods. Psychological Assessment, 7(3), 238. https://doi.org/10.1037/1040-3590.7.3.238

[33] Heflin, H., & Macaluso, S. (2021). Student ınitiative empowers engagement for learning online. Online Learning, 25(3), 230-248. https://doi.org/10.24059/olj.v25i3.2414

[34] Hennig-Thurau, T., Aliman, D. N., Herting, A. M., Cziehso, G. P., Linder, M., & Kübler, R. V. (2023). Social interactions in the metaverse: Framework, initial evidence, and research roadmap. Journal of the Academy of Marketing Science, 51(4), 889-913. https://doi.org/10.1007/s11747-022-00908-0

[35] Herrera-Pavo, M. Á. (2021). Collaborative learning for virtual higher education. Learning, culture and social interaction, 28, 100437. https://doi.org/10.1016/j.lcsi.2020.100437

[36] Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? Educational Psychology Review, 16, 235-266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3

[37] Jeong, H., Hmelo-Silver, C. E., & Jo, K. (2019). Ten years of computer-supported collaborative learning: A meta-analysis of CSCL in STEM education during 2005–2014. Educational Research Review, 28, 100284. https://doi.org/10.1016/j.edurev.2019.100284

[38] Johnson, D. W., & Johnson, R. T. (2009). An educational psychology success story: Social interdependence theory and cooperative learning. Educational Researcher, 38(5), 365-379. https://doi.org/10.3102/0013189X09339057

[39] Johnson, J. P., & Mighten, A. (2005). A comparison of teaching strategies: lecture notes combined with structured group discussion versus lecture only. Journal of Nursing Education, 44(7), 319-322. https://doi.org/10.3928/01484834-20050701-06

[40] Johnson, D. W., & Johnson, R. T. (1987). Learning together and alone: Cooperative, competitive, and individualistic learning (2nd ed.). Prentice-Hall.

[41] Kassem, C. L. (2000). Theory into practice: Best Practices for a school-wide approach to critical thinking instruction. Ramapo College of New Jersey.

[42] Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2), 75-86. https://doi.org/10.1207/s15326985ep4102_1

[43] Kirschner, P. A., Sweller, J., Kirschner, F., & Zambrano R, J. (2018). From cognitive load theory to collaborative cognitive load theory. International Journal of Computer-Supported Collaborative Learning, 13(2), 213-233. https://doi.org/10.1007/s11412-018-9277-y

[44] Kyprianidou, M., Demetriadis, S., Tsiatsos, T., & Pombortsis, A. (2012). Group formation based on learning styles: can it improve students' teamwork?. Educational Technology Research and Development, 60, 83-110. https://doi.org/10.1007/s11423-011-9215-4

[45] Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge University Press.

[46] Li, Y., Xie, H., & Li, D. (2016). Does self-selection work in academic group work? The effect of random group formation on participation and performance. Assessment & Evaluation in Higher Education, 41(7), 966-979.

[47] Liang, C., Majumdar, R., Nakamizo, Y., Flanagan, B., & Ogata, H. (2024). Algorithmic group formation and group work evaluation in a learning analytics-enhanced environment: implementation study in a Japanese junior high school. Interactive Learning Environments, 32(4), 1476-1499. https://doi.org/10.1080/10494820.2022.2121730

[48] Lin, E. C.-L., Chen, S.-L., Chao, S.-Y., & Chen, Y.-C. (2013). Using standardized patient with immediate feedback and group discussion to teach interpersonal and communication skills to advanced practice nursing students. Nurse education today, 33(6), 677-683. https://doi.org/10.1016/j.nedt.2012.07.002

[49] Loyens, S. M., & Gijbels, D. (2008). Understanding the effects of constructivist learning environments: Introducing a multidirectional approach. Instructional Science, 36(5), 351-357. https://doi.org/10.1007/s11251-008-9059-4

[50] Lyall, C., & Meagher, L. R. (2012). A masterclass in interdisciplinarity: Research into practice in training the next generation of interdisciplinary researchers. Futures, 44(6), 608-617. https://doi.org/10.1016/j.futures.2012.03.010

[51] Mercer, N., & Howe, C. (2012). Explaining the dialogic processes of teaching and learning: The value and potential of sociocultural theory. Learning, Culture and Social Interaction, 1(1), 12-21. https://doi.org/10.1016/j.lcsi.2012.03.001

[52] Messick, S. (1995). Validity of psychological assessment: Validation of inferences from persons' responses and performances as scientific inquiry into score meaning. American Psychologist, 50(9), 741. https://doi.org/10.1037/0003-066X.50.9.741

[53] Meyer, H. (2004). Novice and expert teachers' conceptions of learners' prior knowledge. Science education, 88(6), 970-983. https://doi.org/10.1002/sce.20006

[54] Michaelsen, L. K., Knight, A. B., & Fink, L. D. (Eds.). (2023). Team-based learning: A transformative use of small groups in college teaching. Taylor & Francis.

[55] Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis year 1984 to 2002. Journal of Research in Science Teaching, 47(4), 474-496. https://doi.org/10.1002/tea.20347

[56] Mora, H., Signes-Pont, M. T., Fuster-Guilló, A., & Pertegal-Felices, M. L. (2020). A collaborative working model for enhancing the learning process of science & engineering students. Computers in Human Behavior, 103, 140-150. https://doi.org/10.1016/j.chb.2019.09.008

[57] Mozaffari, S. H. (2017). Comparing student-selected and teacher-assigned pairs on collaborative writing. Language Teaching Research, 21(4), 496-516. https://doi.org/10.1177/1362168816641703

[58] National Research Council (1996). From analysis to action: Undergraduate education in science, mathematics, engineering, and technology. National Academy Press.

[59] Nungu, L., Mukama, E., & Nsabayezu, E. (2023). Online collaborative learning and cognitive presence in

mathematics and science education. Case study of university of Rwanda, college of education. Education and Information Technologies, 28(9), 10865-10884. https://doi.org/10.1007/s10639-023-11607-w

[60] Oviedo, M. C. N. (2004). Teacher-student co-construction processes in biology: Strategies for developing mental models in large group discussions [Doctoral dissertation]. University of Massachusetts Amherst.

[61] Park, J., Lee, H., Kim, J., & Zhou, A. Q. (2024). Trajectories of learning attitude profiles in Korean middle school students: Examining developmental patterns and the influence of parenting. Child & Youth Care Forum, 53(2), 485-504. https://doi.org/10.1007/s10566-023-09763-8

[62] Parmar, P. (2022, June 14). Importance of group discussion in teaching. Classplus Growth Blog. Retrieved from https://classplusapp.com

[63] Pfeiffer, J. M., & Butz, R. J. (2005). Assessing cultural and ecological variation in ethnobiological research: the importance of gender. Journal of Ethnobiology, 25(2), 240-278. https://doi.org/10.2993/0278-0771_2005_25_240_acaevi_2.0.co_2

[64] Piaget, J. (1970). Science of education and the psychology of the child. Orion Press.

[65] Prata, M. J., Festas, I., Oliveira, A. L., & Veiga, F. H. (2019). The impact of a cooperative method embedded in a writing strategy instructional program on student engagement in school. Revista de Psicodidáctica (English ed.), 24(2), 145-153. https://doi.org/10.1016/j.psicoe.2018.12.001

[66] Putzeys, K., Van Keer, H., & De Wever, B. (2023). Unknown is not chosen: University student voices on group formation for collaborative writing. Education Sciences, 14(1), 31. https://doi.org/10.3390/educsci14010031

[67] Roseth, C. J., Garfield, J. B., & Ben-Zvi, D. (2008). Collaboration in learning and teaching statistics. Journal of Statistics Education, 16(1). https://doi.org/10.1080/10691898.2008.11889557

[68] Roseth, C. J., Johnson, D. W., & Johnson, R. T. (2008). Promoting early adolescents' achievement and peer relationships: The effects of cooperative, competitive, and individualistic goal structures. Psychological Bulletin, 134(2), 223-246. https://doi.org/10.1037/0033-2909.134.2.223

[69] Sancho-Thomas, P., Fuentes-Fernández, R., & Fernández-Manjón, B. (2009). Learning teamwork skills in university programming courses. Computers & Education, 53(2), 517-531. https://doi.org/10.1016/j.compedu.2009.03.010

[70] Saxton, E., Burns, R., Holveck, S., Kelley, S., Prince, D., Rigelman, N., & Skinner, E. A. (2014). A common measurement system for K-12 STEM education: Adopting an educational evaluation methodology that elevates theoretical foundations and systems thinking. Studies in Educational Evaluation, 40, 18-35. https://doi.org/10.1016/j.stueduc.2013.11.005

[71] Shyiramunda, T. (2023). Datasheet.Excel. Pretest-posttest.Statistical t-test results.xlsx [Dataset]. Figshare. https://doi.org/10.6084/m9.figshare.24486685

[72] Smith, J. (2023). Supporting metacognitive talk during collaborative problem solving: a case study in Scottish primary school mathematics. Education 3-13, 1-16. https://doi.org/10.1080/03004279.2023.2187670

[73] Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practices. Journal of Engineering Education, 94(1), 87-101. https://doi.org/10.1002/j.2168-9830.2005.tb00831.st

[74] Springer, L., Stanne, M. E., & Donovan, S. S. (1999). Effects of small-group learning on undergraduates in science, mathematics, engineering, and technology: A meta-analysis. Review of Educational Research, 69(1), 21-51. https://doi.org/10.3102/00346543069001021

[75] Stanford Teaching Commons (2024). Increasing student engagement. Stanford University. https://teachingcommons.stanford.edu/

[76] Steinert, Y. (2004). Student perceptions of effective small group teaching. Medical Education, 38(3), 286-293. https://doi.org/10.1046/j.1365-2923.2004.01772.x

[77] Strayer, J. F. (2012). How learning in an inverted classroom influences cooperation, innovation and task orientation. Learning Environments Research, 15(2), 171-193. https://doi.org/10.1007/s10984-012-9108-4

[78] Sullivan, G. M., & Feinn, R. (2012). Using effect size—or why the p value is not enough. Journal of Graduate Medical Education, 4(3), 279–282. https://doi.org/10.4300/JGME-D-12-00156.1

[79] Tashakkori, A., Teddlie, C., & Sines, M. C. (2012). Utilizing mixed methods in psychological research. Handbook of Psychology, 2, 428-450. https://doi.org/10.1002/9781118133880.hop202015

[80] Thompson, P. (2013). Learner-centred education and 'cultural translation'. International Journal of Educational Development, 33(1), 48-58. https://doi.org/10.1016/j.ijedudev.2012.02.009

[81] Topping, K. J. (2005). Trends in peer learning. Educational Psychology, 25(6), 631-645.

https://doi.org/10.1080/01443410500345172

[82] Topping, K.J, Buchs, C., Duran, D., & Van Keer, H. (2017). Effective peer learning: From principles to practical implementation. Routledge.

[83] Tsai, C. W., Lee, L. Y., Cheng, Y. P., Lin, C. H., Hung, M. L., & Lin, J. W. (2024). Integrating online metacognitive learning strategy and team regulation to develop students' programming skills, academic motivation, and refusal self-efficacy of Internet use in a cloud classroom. Universal Access in the Information Society, 23(1), 395-410. https://doi.org/10.1007/s10209-022-00958-9

[84] Vygotsky, L. S., & Cole, M. (1978). Mind in society: Development of higher psychological processes. Harvard University Press.

[85] Wang, B., & Li, P. P. (2024). Digital creativity in STEM education: the impact of digital tools and pedagogical learning models on the students' creative thinking skills development. Interactive Learning Environments, 32(6), 2633-2646. https://doi.org/10.1080/10494820.2022.2155839

[86] Wenger, E. (1998). Communities of practice: Learning, meaning, and identity. Cambridge University Press.

[87] Wilkinson, I. A., & Fung, I. Y. (2002). Small-group composition and peer effects. International journal of educational research, 37(5), 425-447. https://doi.org/10.1016/S0883-0355(03)00014-4

[88] Wu, X., Anderson, R. C., Nguyen-Jahiel, K., & Miller, B. (2013). Enhancing motivation and engagement through collaborative discussion. Journal of Educational Psychology, 105(3), 622. https://doi.org/10.1037/a0032792

[89] Yan, J., & Li, L. (2024, June). Board 183: A Case Study of AFL Models on Factors of Engaged Learning in STEM Education. 2024 ASEE Annual Conference & Exposition.

[90] Yang, X. (2023). Undergraduate students' frustrations in collaborative group work [Doctoral dissertation, University of Georgia].

[91] Zuin, V. G., Eilks, I., Elschami, M., & Kümmerer, K. (2021). Education in green chemistry and in sustainable chemistry: perspectives towards sustainability. Green Chemistry, 23(4), 1594-1608. https://doi.org/10.1039/D0GC03313H