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Enhancing students' learning competency in chemistry using Cooperative Learning Activity (CLA) and Processed Mnemonics (PM) Methods: An evaluation

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Abstract

This study aimed to evaluate the effectiveness of Cooperative Learning Activities (CLA) and Processed Mnemonics (PM) in enhancing students' learning competency and overall learning performance in General Inorganic Chemistry and Biochemistry. Using a quasi-experimental design, the research involved 258 first-year Allied Medical Sciences students from Our Lady of Fatima University during the academic year 2024–2025. The experimental group was exposed to CLA and PM strategies, while the control group received traditional lecture-based instruction. Data were collected using a researcher-made formative assessment tool and the "Color Your DNA" activity, both validated and pilot-tested for reliability. Findings revealed that the experimental group significantly outperformed the control group in both objective and open-ended tasks. Statistical analysis showed that CLA and PM strategies positively influenced students' memory retention, conceptual understanding, and higher-order thinking. Additionally, students expressed a strong preference for the innovative learning tools, affirming their relevance and effectiveness. The study concludes that integrating formative, collaborative, and mnemonic-based approaches enhances cognitive processing, engagement, and academic performance in Chemistry. It recommends institutional adoption of CLA and PM to enrich science education and support learner-centered instruction.

Keywords: Assessment; Chemistry; Cooperation; Engagement; Metacognition; Mnemonics

1. Introduction

Teaching and Learning is a cause and effect in nature. If the teaching method used is effective, the student will learn much from the discussion. If it's not, another teaching methodology can be used for remediation. There are teachers nowadays who use teaching media and technology to facilitate learning. Others use group activities or cooperative learning, but there are also some who still use traditional "chalk and talk" method. The traditional instructional communication process such as "chalk and talk," overhead projector (OHP) would no longer be as effective as the use of Cooperative Learning. This is because new modes in teaching and learning are generated, thus giving rise to innovative ways to deliver lessons effectively to the learners (Roque, V.S. and E. Trinidad, 2013). Much activity is given to students to facilitate learning effectively especially to complex topic such as structures of DNA. Deoxyribonucleic acid, more commonly known as DNA, is a complex molecule that contains all of the information necessary to build and maintain an organism (Nature.com, 2014). It is the carrier of genetic information. Usual lecture-type discussions regarding DNA concepts may sometimes lead to students' boredom. Students usually find it odd to study DNA since the structures are only imagined by the students and not actually seen. Several experiments and multimedia instructional materials were common during discussions of the teacher to introduce and explain DNA concepts. But no matter how good the visuals are, students sometimes cannot go beyond what is being described by the teacher. James Watson, who

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won a Nobel Prize as co-discoverer of the double-helix DNA molecule, recognized this when he stated, "Nothing new that is really interesting comes without collaboration." Despite the remarkable achievements of academic teams, the myth of the genius individual still exists; it underlies educational practice that assumes each student should work separately and apart from classmates. While the authors support wholeheartedly the development of individual talents, isolation is not the best path for nurturing them. As Watson noted, creative genius is the product of, and best develops within, cooperative efforts (Johnson, D.W. et. al., 1998). Students' progress and understanding to identify learning needs so that teachers can adjust mode of instruction appropriately can be credited to cognitive development.

One of the defining aspects of cognitive development in childhood is the gradual acquisition of cognitive strategies. Between the ages of 5 and 12, children begin to manage their own learning by focusing attention, regulating study time, monitoring comprehension, and planning communication effectively (Brown & DeLoache, 1978; Paris & Lindauer, 1982, as cited in Paris et al., 1982). These strategies revolve around the self-management of cognitive resources, and an essential developmental task is learning how to plan, select, and regulate behavior in response to instruction and practice. Cognitive development encompasses analytical, computational, and memory skills, which when combined, contribute to the development of Higher Order Thinking Skills (H.O.T.S.). In Chemistry, students frequently encounter challenges with concept-heavy topics such as the periodic table, redox reactions, stoichiometry, and the activity series of metals and non-metals. Since Chemistry often involves formulas and calculations, learning it also entails mastering mathematical procedures. This links Chemistry to critical thinking and problem-solving, requiring students to apply logic, analyze relationships, and even generate new ideas from learned concepts. Despite the current emphasis on problem-solving, many scholars argue for the continued importance of foundational instruction in basic facts and computational skills, noting that these are prerequisites for more advanced mathematical proficiency (Anthony & Knight, 1999; Bana & Korbosky, 1995; Resnick & Ford, 1981, as cited in Manalo et al., 2000). Drill and practice have proven beneficial in reinforcing memory and computational automaticity, which are correlated with overall mathematical competence (Gray & Mulhern, 1995; Bana & Korbosky, 1995). Human memory evolved to efficiently encode vivid, multi-sensory experiences—images, colors, structures, and emotions—but struggles to retain abstract written information (Mindtools.com, 2011). This mismatch underscores the need for teaching strategies that align better with how our brains process and retain knowledge, such as visual tools and mnemonic techniques.

Mnemonic, essentially a memory tool, has long been used to support learning across subjects. While fact mnemonics have been widely studied and applied, process mnemonics—used for remembering rules and procedures in disciplines like spelling, mathematics, trigonometry, and chemistry—are also commonly employed, though less often assessed in formal educational research (Manalo et al., 2000; Santo 2023). Both students and teachers have increasingly turned to mnemonics to make Chemistry topics more manageable, yet the actual evaluation of student learning performance using these tools remains limited. In educational settings, assessment is a critical part of the learning process. Teachers typically rely on summative assessments to evaluate the quantity and quality of student learning at the end of a unit or course. These assessments help determine student promotion, certification, curriculum success, job readiness, and eligibility for further education. However, assessment also serves a formative purpose. As described by the OECD/CERI International Conference (2008), formative assessment consists of continuous, interactive evaluations aimed at identifying student needs and informing instructional adjustments. Teachers who employ formative approaches are better positioned to adapt instruction to diverse learning needs, promote student engagement, and improve overall academic outcomes.

Modern educators face numerous challenges in meeting the educational needs of students, especially given today's volume of information and fast-paced instruction (Kleinheksel, 2003). Students often struggle to recall lessons in the way they recall personal experiences, despite being asked to retain facts, dates, formulas, procedures, and abstract concepts—an outcome of complex brain functions. Consequently, student learning performance is significantly influenced by the teaching methods employed. Teachers must match their instructional techniques to students' learning styles, addressing issues such as motivation, attention span, and retention. This requires using a variety of strategies, including cooperative learning, which has consistently proven to be one of the most successful approaches in educational research.

In light of these considerations, the present study aims to evaluate two key instructional strategies: (1) the use of Cooperative Learning Activities (CLA) and Processed Mnemonics (PM) as teaching methods, and (2) the implementation of a formative assessment-based approach using processed mnemonics and the researcher-made tool "Color Your DNA" to assess learning performance in General Inorganic Chemistry and Biochemistry. Conducted among students from selected high schools and universities, the study also includes a survey measuring students' preferences for both the "Color Your DNA" activity and PM as instructional methods. Previous studies have shown that process mnemonics effectively aid the teaching of procedures and rules, particularly in mathematics and for learners with difficulties. This study hypothesizes that both PM and CLA can improve comprehension and retention in challenging Chemistry topics. Ultimately, the findings aim to support and refine teaching methodologies that enhance student learning outcomes.

Student achievement is closely linked to the presence of quality teachers—those who demonstrate competence, creativity, and commitment in the classroom. Developing these teaching competencies is essential, as effective instruction hinges on methods that actively engage learners. One such method is cooperative learning, which emphasizes simultaneous and ongoing processes of teaching and learning. As Forest (2004) highlights in "Learning and Teaching: The Reciprocal Link," quoting a Chinese proverb, "Tell me and I forget. Show me and I remember. Involve me and I understand." This view, supported by Fincher (1994), frames learning as a progression from ignorance to understanding. Cooperative learning fosters this progression through teacher-student interaction, motivating students and helping teachers unlock their learners' full potential. The origins of this approach date back to the 1950s, when John Coleman found that student competitiveness hindered learning and argued instead for collaboration (David, R. & Demand Media, 2014). Theoretical foundations include Skinner's emphasis on group contingencies, Bandura's social learning theory through imitation, and the social exchange principles of Homans, Thibaut, and Kelley, which focus on the balance of rewards and costs in group settings (Wheelan, 2005). These ideas underpin problem-based and collaborative learning models like that of Johnson et al. (1998), were students co-construct knowledge through natural, informal group interactions. In parallel, enhancing memory retention is equally crucial in effective teaching, particularly through the use of processed mnemonics. The Multi-Store Model of Memory by Atkinson and Shiffrin (1968) outlines three stages of memory: sensory memory, short-term memory (STM), and long-term memory (LTM). Sensory memory briefly holds raw data from the environment—such as light and sound—which are converted into electrical signals interpretable by the brain. STM, or working memory, retains information currently in use, often strengthened through techniques like chunking. Information that is well-encoded progresses to LTM, which stores knowledge over extended periods. The study centers on this final stage, emphasizing how instructional methods like dual coding, rehearsal, and mnemonic aids help learners encode, store, and retrieve information effectively (peoplelearn.homestead.com, 2011). Together, these theories offer a comprehensive framework for understanding how cooperative learning and memory strategies such as processed mnemonics can enhance student learning in a meaningful and lasting way.

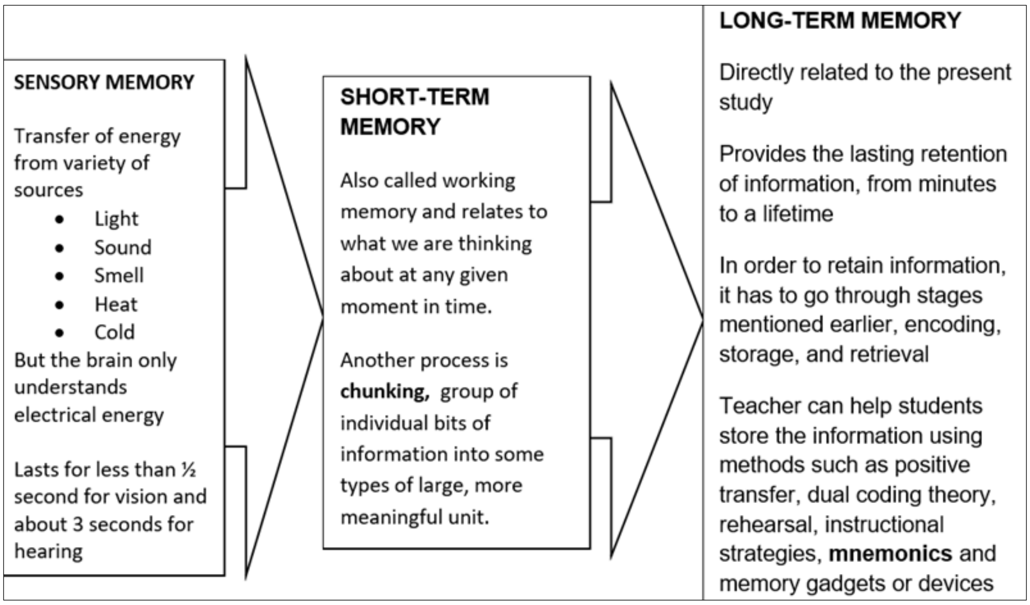

Figure 1 The Link in an Effective Sequence of Memory

Figure 1 illustrates the effective sequence of memory, beginning with sensory memory, which briefly captures environmental stimuli such as light, sound, and temperature. Although this memory lasts only milliseconds for visual input and a few seconds for auditory stimuli, it serves as the initial entry point for information processing. From there, data move into short-term memory—also known as working memory—where actively processed information is held temporarily. A common technique at this stage is "chunking," which organizes bits of data into meaningful units to enhance retention. Finally, information that is encoded successfully progresses into long-term memory, where it can be stored for extended periods—from minutes to a lifetime. This stage is central to the present study, as it investigates how instructional strategies like positive transfer, dual coding, rehearsal, and especially mnemonic aids can help facilitate lasting knowledge. In parallel, formative assessment plays a critical role in supporting this memory development. Introduced by Bloom, Hastings, and Maddaus in 1971, formative assessment emphasizes continuous feedback during instruction, rather than evaluating performance only at the end. It allows teachers to adjust their approaches in real time, supporting student growth through active engagement and reflection. As highlighted in the OECD/CERI International Conference (2008), formative assessment is now widely regarded as an integral part of effective teaching. Together, these theories—on memory, assessment, and instructional strategies—provide the foundation for this study, which aims to evaluate the impact of processed mnemonics and cooperative learning on student performance. Conducted at Our Lady of Fatima University, the study specifically seeks to determine (1) the learning performance of the control group, (2) the learning performance of the experimental group using (a) Cooperative Learning Activities (CLA) and (b) Processed Mnemonics (PM), and (3) whether there is a significant difference in performance between the two groups.

This study further investigates student preferences and performance through the use of two innovative learning tools: the "Color Your DNA" activity and a researcher-made formative assessment evaluation tool. It seeks to determine the level of preference among students toward each tool and to evaluate the performance of both control and experimental groups in the open-ended sections of these assessments. Specifically, the study examines whether significant differences exist in how students from each group perform and respond to these tools. These inquiries are designed to evaluate the combined effectiveness of processed mnemonics and cooperative learning strategies, implemented within a formative assessment framework, in enhancing student learning outcomes. The research paradigm supporting this investigation highlights the integration of Cooperative Learning Activities (CLA) and Processed Mnemonics (PM) as essential components of an activity-based instructional model. This model was applied in the context of key Chemistry topics—including the Periodic Table, Activity Series of Metals, REDOX reactions, Stoichiometry, and DNA sequencing—to foster a more engaging, student-centered learning environment, distinct from traditional lecture-based methods. As represented in the paradigm, the interplay between collaborative engagement and memory-enhancing strategies is expected to improve comprehension and retention. Based on this framework, the study is guided by two core hypotheses: (1) there is no significant relationship between the learning performance scores of the control and experimental groups in relation to the use of CLA and PM; and (2) there is no significant difference in their performance within the open-ended tasks of both the "Color Your DNA" activity and the researcher-made formative assessment tool.

This study is significant in examining how processed mnemonics, formative assessment, and cooperative learning strategies can jointly enhance instructional effectiveness. Processed mnemonics—through tools such as acronyms, keyword associations, and models—not only aid memory recall but also simplify complex topics for long-term retention. According to pmemory.com (2011), the brain remains active even at rest, and retention is maximized when information is linked to emotions and repetition. Formative assessment complements this by providing timely feedback and instructional adjustments, supporting reflective learning and student growth. In contrast to summative assessments, formative approaches promote deeper engagement and help students identify their learning needs. Cooperative learning further enriches this environment, as evidenced by multiple studies (Stevens & Slavin, 1995; Bramlet, 1994; Megnin, 1995; Webb et al., 1995; Glassman, 1989; Johnson et al., 1986; Crosby & Owens, 1993), which show improvements in achievement, participation, and mutual respect across diverse student groups. It has proven particularly effective for students who struggle in traditional lecture-based settings (Ajaja & Eravwoke, 2010). These findings suggest that administrators, department heads, and faculty can use the study's results to strengthen supervision, refine pedagogy, and foster higher-order thinking. Students, in turn, benefit from a more engaging and accessible Chemistry learning experience. Institutions may also apply the findings to enhance curriculum alignment with quality assurance and licensure standards. Conducted among Nursing and Psychology students at Our Lady of Fatima University using purposive convenience sampling, the study focused on learners in Chemistry-intensive programs. For greater generalizability, future research is encouraged to include participants from teacher education institutions across other regions.

2. Literature review

Students are constantly engaged in the process of learning, and while teachers recognize the individual differences among learners, they often rely on a variety of teaching strategies in the belief that these will equip students with the knowledge needed for daily life. However, even seemingly appropriate teaching methods can fall short if they do not align with the learners' needs. Teachers must consider factors such as students' learning styles, age, behavior, thinking patterns, gender, content complexity, and preferences. In modern pedagogy, the role of the teacher has shifted from being an authority figure to serving as a resource person and facilitator. Teachers are encouraged to be more responsive to individual learning differences and to help students develop independent learning strategies that reduce reliance on direct instruction. One such instructional strategy that has gained attention is the use of processed mnemonics. Teaching is a profession that evolves with experience, and recent research highlights the effectiveness of mnemonic strategies in improving memory and learning outcomes. According to Mastropieri, Sweda, and Scruggs (2000), and Kleinheksel et al. (2003), mnemonics are widely used by teachers to help students remember essential information across various subjects, including English, foreign languages, science, social studies, and math. Mastropieri and Scruggs (1991, as cited by Kleinheksel et al., 2003) emphasize that these strategies support students in recalling vocabulary, facts, and concepts effectively. A meta-analysis by Verhaeghen et al. (2012) examined the impact of memory training among elderly individuals aged 60 and above. The results revealed that training groups achieved significantly greater gains in episodic memory tasks (0.73 SD) compared to control (0.38 SD) and placebo (0.37 SD) groups. Factors such as younger participant age and group treatment positively influenced outcomes, while session duration negatively affected treatment gains. Interestingly, the type of mnemonic used and pretraining method did not significantly affect treatment results. Further supporting the potential of mnemonics, Manalo et al. (2000) investigated the use of process mnemonics in teaching students with mathematics learning disabilities (LD). Their study found that process mnemonics were effective in teaching procedures and rules in math, building on earlier evidence that both fact and process mnemonics can aid learners with LD. These findings suggest that mnemonic-based instruction can be a valuable tool for diverse learners and learning contexts.

A study published in the Journal of Experimental Child Psychology titled “Learning the Functional Significance of Mnemonic Actions: A Microgenetic Study of Strategy Acquisition” by Paris, Newman, and McVey (1982) of the University of Michigan explored how children acquire memory strategies through metacognitive learning. In this microgenetic study, seven- and eight-year-olds completed memory trials over five consecutive days, involving 24-picture recall tasks. The first two days served as baseline trials, followed by a day of strategy training, and two final days for unprompted assessments. Children were taught labeling, rehearsal, grouping, self-testing, and blocked recall. While half were instructed only to perform the techniques, the other half received elaborated feedback on their utility. The elaborated group demonstrated significantly better recall, strategic behavior, and metacognitive understanding. Path analysis indicated that training and metacognitive awareness directly influenced recall and sorting strategies. This study emphasized how understanding the value of mnemonic strategies enhances their adoption as self-directed learning tools. However, while these findings support the effectiveness of mnemonic instruction, prior research did not fully assess students’ progress using processed mnemonics over time, nor did it incorporate a structured assessment-based approach to measure their impact. Addressing this gap, David Steer (2011) of the University of Akron highlighted in his study, “An Assessment-Based Approach for Evaluating Learning in Natural Science General Education Courses,” the effectiveness of embedding formative and summative assessments into course instruction. By integrating content mastery and higher-order thinking tasks—such as constructing geologic cross-sections to demonstrate knowledge of rock processes and geologic time—students improved in analytical reasoning and understanding of science’s societal relevance. This multi-tiered assessment approach provided meaningful insights into educational outcomes. Supporting this, the OECD/CERI Conference paper “Assessment for Learning, Formative Assessment” underscored the importance of aligning teaching and assessment strategies to national education goals, highlighting the value of formative assessment in improving instructional quality. Similarly, Buldu and Buldu (2009), in their study “Concept Mapping as a Formative Assessment in College Classrooms,” demonstrated that concept mapping enhances student learning and satisfaction, particularly in teacher education. Their findings suggest that concept mapping, when used as a formative assessment tool rather than a summative task, fosters meaningful dialogue among students and between instructors, reinforcing its value in deepening learning and improving educational outcomes.

Cooperative learning is an instructional approach wherein students work together in small, diverse groups to accomplish shared learning goals without the need for constant teacher supervision. Within these groups, students engage in guided activities that help them form their own understanding of specific topics. Common cooperative learning strategies include the Jigsaw method, Grid, 3-step interviews, roundtable discussions, and even teacher-modified formats tailored for high school and college learners (Holt, Rinehart and Winston, 2014). Despite its proven effectiveness, cooperative learning is often underutilized by college instructors. A compelling example is the case of David Kroetsch and Pawel Lukaszynski, two high school students from Resurrection Catholic Secondary School in Ontario, who collaborated to build a robot for the 1997 International Aerial Robotics Competition. Their project involved designing a robot capable of autonomous flight, object recognition, retrieval, and return landing. Fueled by shared interests in aviation, hardware, and software, their teamwork over nine months resulted in a robot that earned 182 out of 200 points for innovation—making them the only high schoolers to win in a field of older competitors (Johnson et al., 1998). This example underscores the transformative power of academic teamwork and highlights the need for broader adoption of cooperative learning at the tertiary level. The studies and literature cited significantly informed and supported the present research, enriching the interpretation of findings and offering deeper insight into the phases of the study.

3. Methodology

This study employed a quasi-experimental research design using a post-test analytical technique to evaluate students' learning performance. A researcher-made formative assessment tool and the “Color Your DNA” activity served as the primary instruments for data collection. The quasi-experimental approach was chosen due to its applicability in settings where random assignment is not possible, allowing the researcher to examine treatment effects among naturally formed groups. The study was conducted during the academic year 2024–2025 and involved 258 first-year Allied Medical Sciences students taking General Chemistry and Biochemistry, along with four Chemistry faculty members. A purposive-quota sampling method was used, targeting a total of 458 participants. The main instrument consisted of two parts: Part I gathered student demographic information, and Part II assessed learning performance based on analytical, computational, and verbal language skills in Chemistry. For General Chemistry, students were given the assessment after lessons taught using processed mnemonics covering the periodic table, activity series of metals, atomic structure, and electronic configuration. Open-ended questions were integrated to develop higher-order thinking skills (HOTS), with scoring rubrics provided to ensure objectivity. For Biochemistry, the "Color Your DNA" activity was used to explain DNA structure and sequencing; it was time-constrained (30 minutes) and designed for collaborative learning, followed by five multiple-choice questions. Prior to implementation, both tools underwent pilot testing and were evaluated by content experts to ensure reliability and validity in terms of content, internal consistency, criterion relevance, and face validity. Items were analyzed, revised, and finalized with expert guidance, including input from the researcher's academic adviser.

Prior to distributing the assessment tools, the researcher sought formal permission from Deans of various colleges through official request letters. Upon approval, Chemistry instructors were asked to deliver uniform lessons on key General Chemistry topics—such as the periodic table, redox reactions, activity series of metals, and electronic configuration—as well as Biochemistry concepts including DNA sequencing and Polymerase Chain Reaction. These teachers also administered the researcher-made assessment tool and the "Color Your DNA" activity to their students. After the midterm of the college students, the tools were collected for analysis. Data were gathered, tabulated, ranked, and interpreted using both descriptive and inferential statistics. Frequency counts and percentages were used to determine students' preference for CLA and PM, while weighted means assessed performance in quantitative and qualitative skills. A paired t-test was applied to compare the mean scores of controls and experimental groups. To ensure accuracy and efficiency, the Statistical Package for Social Sciences (SPSS) was used to process all data through coding, data entry, program selection, and execution of statistical analysis.

4. Results and discussion

4.1. Level of Learning Performance of the Control Group

Table 1 Learning Performance of the Control Group

Assessment Activities	Mean Score	Mean Rating (%)
Color Your DNA	4.09	40.87%
Researcher-made Tool	4.44	44.40%

Table 1 shows that the control group performed at a relatively low level in both assessments, with mean ratings well below 50%. These results indicate that students taught through traditional methods struggled to grasp Chemistry content effectively. The low scores reflect difficulty in recalling or applying information learned through lecture-based instruction. This suggests that the conventional approach failed to promote meaningful engagement or retention of concepts.

The findings in Table 1 support the argument that traditional "chalk and talk" teaching methods are insufficient for complex subjects like Chemistry. This aligns with Mindtools.com (2011), which states that abstract written material is harder for students to retain without interactive strategies. Since control group students were not exposed to mnemonic aids or cooperative activities, their cognitive processing and memory reinforcement were limited. These results highlight the need for more engaging and student-centered approaches to improve learning performance.

4.2. Level of Learning Performance of the Experimental Group

Table 2 reveals that the experimental group exhibited excellent performance across both assessments using Cooperative Learning Activities (CLA) and Processed Mnemonics (PM). The scores ranged from 89% to 95%, demonstrating a clear understanding of the content delivered through these innovative strategies. These high mean ratings imply increased motivation, comprehension, and skill application among students exposed to active learning. The success of CLA and PM indicates their potential in significantly improving Chemistry instruction.

Table 2 Learning Performance of the Experimental Group

Assessment Activities	CLA Mean Score	CLA Rating (%)	PM Mean Score	PM Rating (%)
Color Your DNA	9.51	95.13%	9.23	92.32%
Researcher-made Tool	8.95	89.53%	8.92	89.22%

The results in Table 2 validate the effectiveness of integrating CLA and PM in science education. These approaches facilitated engagement and deeper cognitive processing, supporting the findings of Johnson et al. (1998) and Manalo et al. (2000). CLA encourages peer interaction and collaborative problem-solving, while PM enhances memory and concept recall through structured aids. Together, they create an enriched learning environment that promotes both foundational understanding and higher-order thinking.

4.3. Significant Difference in Learning Performance Between Control and Experimental Groups

Table 3 Significance Test Results

Proposed Teaching Strategies	Calculated Value	Critical Value	Decision
Utilization of CLA	66.39	1.97	Reject the Ho
Utilization of PM	57.51	1.97	Reject the Ho

Table 3 shows that for both teaching strategies, the calculated t-values were lower than the critical values, leading to the rejection of the null hypothesis. This suggests that the difference in learning performance between the control and experimental groups is statistically significant. Students taught using CLA and PM performed considerably better than those taught through traditional means. The results confirm that the applied strategies made a meaningful impact on learning outcomes.

The statistical evidence in Table 3 emphasizes the transformative effect of innovative instructional methods. According to OECD/CERI (2008), formative assessment and interactive learning enhance student achievement and reduce learning disparities. The significant improvement under CLA and PM validates the theoretical foundation behind using collaborative and mnemonic strategies in complex subject areas. These results advocate for their inclusion in modern teaching practices, especially in subjects requiring cognitive reinforcement.

4.4. Level of Preference of the Respondents Toward Teaching Strategies

Table 4 Students' Preference Ratings

Assessment Activities	Weighted Mean	Interpretation
Color Your DNA	4.28	Agree
Researcher-made Tool	4.31	Agree

As shown in Table 4, students agreed positively with the use of both the "Color Your DNA" activity and the researcher-made assessment tool. The weighted mean scores reflect a favorable perception toward the learning tools used in the experimental setup. Students likely found these tools engaging, relevant, and effective in supporting their understanding of the lesson. Their approval is indicative of increased motivation and active participation.

Table 4 aligns with findings from Kleinheksel et al. (2003) and Buldu & Buldu (2009), who emphasized that learner-friendly tools improve satisfaction and classroom dialogue. When students perceive learning tools as effective, they are more likely to be engaged and retain information. The preference for PM and CLA reflects their accessibility and usefulness in visualizing and internalizing abstract Chemistry concepts. This highlights the pedagogical value of incorporating learner-centered tools in science education.

4.5. Control Group Performance in the Open-Ended Assessment

Table 5 Control Group's Open-Ended Scores

Assessment Activities	Weighted Mean	Interpretation
Color Your DNA	2.89	Average
Researcher-made Tool	2.62	Average

Table 5 shows that the control group performed at an average level in open-ended tasks, indicating limited development of higher-order thinking skills. The scores suggest that students were able to provide only basic responses or recall, lacking depth or application. This reflects a surface-level understanding of the topics covered. Without structured guidance, learners struggled to analyze or synthesize information independently.

The average performance recorded in Table 5 highlights the challenges of passive learning in developing critical and creative thinking. Traditional instruction often falls short in eliciting comprehensive and analytical responses. This confirms the observations of Anthony & Knight (1999), who stressed the importance of reinforcing computation and cognition through active practice. The results call for the inclusion of open-ended activities supported by structured scaffolding like CLA and PM.

4.6. Experimental Group Performance in the Open-Ended Assessment

Table 6 Experimental Group's Open-Ended Scores

Assessment Activities	Weighted Mean	Interpretation
Color Your DNA	4.52	Excellent
Researcher-made Tool	4.63	Excellent

As presented in Table 6, the experimental group achieved excellent ratings in both open-ended assessment activities. These scores reflect their strong analytical thinking, conceptual understanding, and ability to apply knowledge creatively. The activities helped students go beyond rote memorization and encouraged critical evaluation. This level of performance demonstrates the instructional power of CLA and PM.

The findings in Table 6 support the view that structured, active learning strategies significantly enhance metacognitive abilities. Students exposed to PM and CLA were not only able to recall content but also engage in deeper processing. Paris et al. (1982) emphasized the role of metacognitive awareness in strategy acquisition, which was evident in these results. This further validates the approach of combining memory-enhancing techniques with collaborative learning for complex topics like Chemistry.

4.7. Significant Difference in Open-Ended Assessment Performance

Table 7 T-Test for Open-Ended Performance

Test Statistic	Calculated Value	Critical Value	Decision
t-test	56.92	1.97	Reject Ho

Table 7 confirms a significant difference between the control and experimental groups in their open-ended task performance. The calculated value supports the conclusion that the intervention using CLA and PM positively influenced students' ability to respond thoughtfully. This means the experimental group not only scored higher but demonstrated better cognitive engagement. Their enhanced performance is statistically meaningful and not due to chance.

The statistical results in Table 7 underscore the importance of formative, interactive instruction. Ajaja & Eravwoke (2010) argued that students benefit most when teaching strategies align with their learning needs. CLA and PM provided cognitive scaffolding that traditional methods lacked. These findings support the integration of assessment-driven, memory-based strategies to foster deeper and more measurable learning.

5. Conclusion

The findings of this study clearly establish that the use of Cooperative Learning Activities (CLA) and Processed Mnemonics (PM), when integrated into Chemistry instruction, significantly enhances students' learning performance and metacognitive development. Compared to traditional teaching methods, these strategies not only improved students' ability to recall, understand, and apply content knowledge but also fostered higher-order thinking skills, as evidenced by the experimental group's outstanding scores in both objective and open-ended assessments. Moreover, students expressed strong preference and satisfaction toward the researcher-made formative assessment tools and the “Color Your DNA” activity, indicating that these interventions were not only effective but also engaging and accessible. Statistical analyses confirmed that these teaching innovations had a significant positive impact on both quantitative and qualitative indicators of learning. Overall, the study underscores the pedagogical value of adopting learner-centered, formative, and collaborative teaching methods in science education. The integration of CLA and PM provided cognitive scaffolds that helped students go beyond surface-level learning, supporting memory retention, analytical reasoning, and problem-solving capabilities. By aligning instruction with students' cognitive development and learning preferences, educators can unlock greater academic potential and foster metacognitive awareness among learners. The results affirm that instructional innovation rooted in sound cognitive theories can lead to meaningful and lasting learning outcomes.

Recommendations

In light of the study's results, it is strongly recommended that Chemistry teachers, especially at the tertiary and senior high school levels, incorporate both Cooperative Learning Activities and Processed Mnemonics into their instructional approaches. These methods should be used not as occasional supplements but as integral parts of lesson planning and delivery—particularly in content-heavy topics such as stoichiometry, redox reactions, and DNA structure. School administrators and department heads are encouraged to provide training, resources, and curriculum space for these strategies, ensuring that formative assessment tools and collaborative learning opportunities are systematically implemented. Furthermore, instructional materials like the “Color Your DNA” activity and researcher-designed formative assessments should be institutionalized and continually improved to support deeper student engagement. It is also advisable for educators to collect ongoing feedback from students to refine these strategies and align them with evolving classroom needs. Lastly, future researchers are encouraged to replicate and expand this study across other academic institutions and disciplines to validate its generalizability and further enrich the educational framework supporting cognitive-based learning.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] Ajaja, O., & Eravwoke, O. (2010). Effects of cooperative learning strategy on junior secondary school students' achievement in integrated science. Electronic Journal of Science Education, 14(1).

[2] Anthony, G., & Knight, G. (1999). Teaching for understanding and memory in year 4-5 mathematics: Research report for the Ministry of Education. Massey University.

[3] Bramlett, R. (1994). Implementing cooperative learning: A field study evaluation.

[4] Brown, A. L. (1982). Learning and development: The problems of compatibility, access, and induction. Human Development, 25, 89–115.

[5] Brown, A. L., & DeLoache, J. S. (1978). Skills, plans, and self-regulation. In R. Siegler (Ed.), Children's thinking: What develops? Erlbaum.

[6] Buldu, M., & Buldu, N. (2010). Concept mapping as a formative assessment in college classrooms: Measuring usefulness and student satisfaction. Higher Colleges of Technology, Al Ain Women's College.

[7] Cruz, D. M. N. D. (2023). The quest for adventure: A Tourist's perspective on choosing attractions in Zambales, Philippines. World Journal of Advanced Research and Reviews, 17(3), 831-841

[8] Coppola, B. C. (2002). Writing a statement of teaching philosophy. College Science Teaching.

[9] Cornell Institute for Biology Teachers. (n.d.). Lego DNA lab. cibt.bio.cornell.edu/labs_and_activities/images/LegoLab.pdf

[10] Crosby, M. S., & Owens, E. M. (1993). The disadvantages of tracking and ability grouping: A look at cooperative learning as an alternative. National Dropout Prevention Center Bulletin, 5, 1–8.

[11] Drummond, C. (1999). Skills for the future. The Science Teacher, 66(4).

[12] Fincher, C. (1994). Teaching and learning in the college classroom. In K. A. Feldman & M. B. Paulson (Eds.), Learning theory and research. Ginn Press.

[13] Forest, S. (2004). Learning and teaching: The reciprocal link. The Journal of Continuing Education in Nursing, 35(2).

[14] Gillies, R. M. (2009). Teachers' reflections on cooperative learning: Issues of implementation. Teaching and Teacher Education, 26. https://doi.org/10.1016/j.tate.2009.10.034

[15] Glassman, P. (1989). A study of cooperative learning in mathematics, writing and reading in the intermediate grades: A focus upon achievement, attitudes, and self-esteem by gender, race, and ability group (Doctoral dissertation, Hofstra University).

[16] Gray, C., & Mulhern, G. (1995). Does children's memory for addition facts predict general mathematical ability? Perceptual and Motor Skills, 81, 163–167.

[17] Holt, Rinehart, & Winston. (2014). Professional reference for teachers. http://go.hrw.com/resources/go_sc/gen/HSTPR010.PDF

[18] Johnson, D. W., & Johnson, R. T. (1989). Cooperation and competition: Theory and research. Interaction Book Company.

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

[20] Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). Cooperative learning returns to college: What evidence is there that it works? http://www.sjsu.edu/advising/docs/CooperativeLearning.pdf

[21] Kleinheksel, K. A., et al. (2003). Enhancing student learning and social behavior through mnemonic strategies. Council for Exceptional Children.

[22] Manalo, E., Bunnell, J. K., & Stillman, J. A. (2000). The use of process mnemonics in teaching students with mathematics learning disabilities.

[23] Mastropieri, M. A., & Scruggs, T. E. (1991). Teaching students ways to remember: Strategies for learning mnemonically. Brookline Books.

[24] Mastropieri, M. A., Sweda, J., & Scruggs, T. E. (2000). Putting mnemonic strategies to work in the inclusive classroom. Learning Disabilities Research and Practice.

[25] Megnin, J. (1995). Combining memory and creativity in teaching mathematics. Teaching PreK-8, 25(6), 48–49.

[26] Mindtools. (2011). Memory: Improving your memory. http://www.mindtools.com/memory.html

[27] Nature.com. (n.d.). What is DNA? http://www.nature.com/scitable/topicpage/introduction-what-is-dna-6579978

[28] Northwest Regional Professional Development Program. (n.d.). Evaluation Form. http://nwrpdp.com/documents/RPDP_Forms/RPDP%20Standard%20Evaluation%2010-11.pdf

[29] OECD. (2005). Formative assessment: Improving learning in the secondary classrooms. Policy Brief.

[30] OECD/CERI. (2008). Assessment for learning: Formative assessment. Learning in the 21st century: Research, innovation and policy.

[31] Paris, S. G., & Lindauer, B. K. (1982). The development of cognitive skills during childhood. In B. Wolman (Ed.), Handbook of developmental psychology. Prentice-Hall.

[32] Paris, S. G., Newman, R. S., & McVey, K. A. (1982). Learning the functional significance of mnemonic actions: A microgenetic study of strategy acquisition. Journal of Experimental Child Psychology, 34, 490–509.

[33] PeopleLearn. (2011). Chapter 5: Memory strategies. http://peoplelearn.homestead.com/BEduc/Chapter_5.pdf

[34] Pmemory. (2011). What is GMS? http://www.pmemory.com/student-area/GMS_Manual/What_is_GMS.htm

[35] Resnick, L. B., & Ford, W. (1981). The psychology of mathematics for instruction. Lawrence Erlbaum Associates.

[36] Roque, V. S., & Trinidad, E. C. (2013). Application of "Color Your DNA" activity and flash games as a teaching tool in cytogenetics to enhance teaching and learning in the classroom.

[37] Santos, A. (2023). Human resource lens: perceived performances of ISO 9001: 2015 certified service firms. *International Journal of Human Capital in Urban Management*, *8*(2), 229-244.

[38] Schon, D. A. (1987). Educating the reflective practitioner. Jossey-Bass.

[39] Slavin, R. E. (1996). Research on cooperative learning and achievement: What we know, what we need to know. Contemporary Educational Psychology, 21, 43–69.

[40] Steer, D. (2011). An assessment-based approach for evaluating learning in natural science general education courses. University of Akron.

[41] Stevens, R. J., & Slavin, R. E. (1995). The cooperative elementary school: Effects on students' achievement, attitudes, and social relations. American Educational Research Journal, 32(2), 321–351.

[42] Sweitzer, F. H. (2003). Getting off to a good start: Faculty development in professional programs. The Journal of Continuing Education in Nursing, 34(6).

[43] Verhaeghen, P., Marcoen, A., & Goossens, L. (2012). Improving memory performance in the aged through mnemonic training: A meta-analytic study. Psychology and Aging, 7(2), 242. http://psycnet.apa.org/journals/pag/7/2/242/

[44] Web Resources (APA Style)

[45] Webb, N., Trooper, J., & Fall, R. (1995). Constructive activity and learning in collaborative small groups. Journal of Educational Psychology, 87(34), 406–423.

[46] Wheelan, S. A. (2005). The handbook of group research and practice. Sage Publications.

[47] Your Genome. (n.d.). DNA sequencing bracelets. www.yourgenome.org/downloads/pdf/.../seq/FT_sequence_bracelets.pdf