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STOICHIOCARDS: A metacognitive problem-solving guide in stoichiometric calculations of solutions

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Abstract

This study aimed to develop and determine the effectiveness of STOICHIOCARDS, a metacognitive problem-solving guide, in enhancing Grade 12 STEM learners' proficiency in concentration and stoichiometric calculations of solutions, and to evaluate its acceptability using the LRMDS evaluation tool. A quantitative pre-experimental one-group pretest–posttest design was employed with thirty-one Grade 12 STEM students from a National High School in Calumpit, Bulacan. The School Quality Assurance Team evaluated the material, while learners completed validated pretests, posttests, and a perception survey. Descriptive statistics measured performance and acceptability, and a paired samples t-test analyzed score differences. STOICHIOCARDS, developed through the ADDIE model and grounded in constructivist, cognitive load, and experiential learning theories, was rated very satisfactory across all domains. By integrating Concept, Guide, Reflect, and Challenge Cards with structured STAMP and SPICE strategies, the intervention offered scaffolded, problem-based learning that reduced cognitive load and strengthened metacognitive skills. Learners showed significant improvement (pretest $M = 8.55$; posttest $M = 23.71$; $p < 0.0001$). The study concludes that STOICHIOCARDS is an effective, acceptable instructional material that promotes independent learning, critical thinking, and confidence in chemistry.

Keywords: Metacognitive Problem-Solving; Stoichiometric Calculations; Instructional Material Development; ADDIE Model

1. Introduction

In the context of Education 4.0, problem-solving skills are recognized as essential competencies that go beyond content knowledge, fostering critical thinking, adaptability, and collaboration [1], [2]. According to the Asian Development Bank [3], the Philippine education system is actively evolving to equip students with the necessary skills to thrive in innovation-driven industries. Despite this priority, Filipino learners continue to score below the global average in science, as shown in the Programme for International Student Assessment (PISA 2022) results and the National Achievement Test [4], [5]. At the local level, Sta. Lucia National High School in Calumpit, Bulacan faces unique challenges, with recurring flooding and class suspensions contributing to learning gaps.

The necessity for such interventions was underscored by the 2022 results of the Programme for International Student Assessment (PISA), which revealed that Filipino students continued to perform below the global average in science literacy. The Philippines scored an average of 373 in science, significantly lower than the OECD average of 485, ranking 77th out of 81 participating countries [4]. According to the Department of Education, this result indicates that Filipino learners are approximately five to six years behind their international counterparts in terms of scientific competencies [5]. These findings highlighted the urgent need for educational strategies that enhance scientific literacy and problem-solving skills. In response, the researcher developed and implemented the intervention material to contribute to

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addressing these learning gaps by equipping students with tools that fostered a deeper conceptual understanding and the ability to solve complex scientific problems effectively.

The Division Education Development Plan 2022 (DEDP) of the Schools Division of Bulacan also highlights the persistent challenges in science education. Data from the Grade 12 National Achievement Test (NAT) results reveal that science continues to have one of the lowest mean percentage scores (MPS), with 31.26% in SY 2017-2018 and 32.11% in SY 2018-2019. These figures underline the need for focused interventions to improve foundational and advanced science skills among learners [6]. The DEDP also emphasizes the importance of nurturing 21st-century skills, such as critical thinking and problem-solving, to prepare learners for higher education, employment, and entrepreneurship.

During the school year 2023–2024, the performance of Grade 12 STEM learners at Sta. Lucia National High School in General Chemistry 2, as reflected in the quarterly assessments, revealed a concerning trend. In the first quarter, 84.62% of students met or exceeded the 60% minimum proficiency level, followed by 73.08% in the second quarter. However, a sharp decline was observed in the third quarter, with only 57.69% of learners attaining the minimum proficiency level. Although the fourth quarter showed a slight recovery, with 80.77% meeting the benchmark, the third quarter performance signaled a significant challenge in maintaining consistent academic achievement. This drop pointed to persistent difficulties in mastering specific competencies, particularly those covered during the third quarter.

Among these, the two least learned competencies were identified as "perform stoichiometric calculations for reactions in solution" (STEM_GC11PP-IIId-f-112), and "use different ways of expressing concentration of solutions: percent by mass, mole fraction, molarity, molality, percent by volume, percent by mass, and ppm" (STEM_GC11PP-IIId-f-111). These competencies, which are prerequisite to one another, require a combination of conceptual understanding and computational skills. The consistently low performance in these areas reflected a broader concern within the national education system, where many learners struggle with problem-solving in chemistry, particularly in stoichiometry and solution concentration.

In particular, Senior High School students in the Philippines face significant challenges in mastering stoichiometric calculations and expressing concentrations of solutions. These difficulties are attributed to misconceptions about chemical concepts, inadequate mathematical skills, and limited problem-solving abilities (Taha, 2014). This difficulty reflects persistent gaps in problem-solving proficiency, as seen in declining assessment results and low performance in international benchmarks such as PISA [4].

In response to these challenges, the study introduced STOICHIOCARDS: A Metacognitive Problem-Solving Guide, an innovative instructional resource developed to enhance learners' proficiency in stoichiometric calculations of solutions. STOICHIOCARDS was specifically designed to address the learning gaps in the two aforementioned competencies by providing structured, reflective, and interactive learning experiences. The intervention was grounded in well-established educational theories: Constructivist Learning Theory, Cognitive Load Theory, Kolb's Experiential Learning Theory, Metacognitive Theory, and Social Learning Theory. These theoretical foundations ensured that learners could build understanding through active engagement, manage cognitive load efficiently, experience learning through doing and reflection, regulate their own learning, and benefit from collaborative and observational learning.

The localized material included four key components. The Concept Card introduced fundamental concepts such as molarity, molality, mole fraction, and percent concentration formats, helping learners anchor their understanding before engaging in problem-solving. The Guide Card featured structured problem-solving methods—STAMP (Spot, Target, Adjust, Match, Plug) for concentration problems, and SPICE (Start, Pick, Identify, Convert, End) for stoichiometry—aimed at reducing cognitive overload and promoting self-monitoring. The Challenge Card provided tiered tasks, from simple warm-up problems to real-life warrior-level applications, allowing for differentiated instruction and productive struggle. Lastly, the Reflect Card offered metacognitive prompts, self-checklists, and self-rating tools to help students reflect on their progress and regulate their own learning.

STOICHIOCARDS effectively contextualized and scaffolded the learning of complex chemical calculations, transforming what was once a difficult topic into an approachable and engaging learning experience. It supported the strategic directions of DepEd Bulacan, particularly in the localization of instruction and the enhancement of science education through initiatives such as Project Basic Science Skills. Furthermore, the material aligned with the Division Education Development Plan [6], contributing to the target of a 60% improvement in literacy, numeracy, and science skills. International best practices were also observed through the development of 21st-century skills like critical thinking, collaboration, and communication. Ultimately, STOICHIOCARDS served as a structured learning companion that empowered students to become confident, independent, and reflective problem-solvers in General Chemistry 2.

Vo et al. [7] conducted a systematic review exploring problem-solving scaffolds in general chemistry, analyzing 20 studies published between 2000 and 2024. Their review synthesized current knowledge on scaffolding approaches and provided a framework for classifying scaffolds based on goals and implementation modes. Findings revealed that scaffolding supports resource activation, argumentation, and both content-specific and metacognitive processes, with effectiveness influenced by instructional design, teacher expertise, and scaffold fading. This aligns with the interactive nature of the STOICHIOCARDS, which incorporated step-by-step guided activities and scaffolded challenges that promoted hands-on engagement and helped learners break down complex chemical problems into manageable parts.

Güner and Erbay [8] investigated the metacognitive strategies that middle school students employed while solving non-routine word problems. Their study revealed that students with higher metacognitive skills were more successful in problem-solving, as they were able to use appropriate strategies, mathematical notations, and logical reasoning, while students with weaker metacognitive skills struggled to understand problems, choose suitable strategies, and correct errors in their solutions. These findings emphasize the importance of self-monitoring and reflection in enhancing problem-solving abilities. In alignment with this, the STOICHIOCARDS included a Reflect Card that prompted learners to assess their own understanding, rate their performance, and identify steps or concepts they found challenging. By incorporating such metacognitive features, STOICHIOCARDS fostered self-awareness and encouraged learners to develop strategies for improving their problem-solving skills.

Saro et al. [9] examined the effectiveness of contextualized and localized science teaching and learning materials in improving students' learning performance. Their experimental study revealed that students who engaged with contextualized and localized materials demonstrated significantly higher performance compared to those who did not, highlighting the value of tailoring learning experiences to students' immediate environment and culture. These findings reinforce the importance of integrating relevant and relatable contexts into science education. In alignment with this principle, the STOICHIOCARDS presented real-life scenarios in its Challenge Cards, particularly in the "Warrior Level" tasks. These challenges used locally relevant situations—such as preparing mixtures or measuring chemical substances in everyday contexts—that helped students connect abstract chemistry concepts with practical applications in their daily lives.

Zhou et al. [10] investigated the effects of task-based learning (TBL) in chemistry experiment teaching on high school students' critical thinking skills in Xi'an, China. Their experimental study revealed that students taught through TBL showed significant improvement in analyticity skills compared to those taught through traditional lecture-based methods. The findings highlighted that structured, task-oriented activities not only enhanced engagement but also promoted deeper thinking and application of knowledge. This aligns with the task-based design of the STOICHIOCARDS, which offered progressively challenging exercises to reinforce students' understanding of chemical principles. By integrating guided and independent practice, STOICHIOCARDS allowed learners to revisit and apply concepts, thereby strengthening both problem-solving and critical thinking skills.

Collectively, these studies reinforced the idea that using interactive, metacognitive, and contextualized strategies in science education can significantly improve students' understanding, problem-solving abilities, and long-term retention of complex concepts. The STOICHIOCARDS, with its structured design incorporating Concept, Guide, Challenge, and Reflect Cards, addressed key learning challenges in chemistry by engaging students in step-by-step problem-solving methods such as STAMP (Spot, Target, Adjust, Match, Plug) and SPICE (Start, Pick, Identify, Convert, End). These systematic approaches lightened cognitive load and made learning more manageable, particularly for students with diverse skill levels.

The study aimed to develop and evaluate the effectiveness of the STOICHIOCARDS in enhancing problem-solving skills in stoichiometry among Senior High School (SHS) learners. Specifically, it assessed the acceptability of the STOICHIOCARDS in terms of content, format, organization, and accuracy. The study also measured learners' proficiency in stoichiometric calculations before and after using the material and determined the significance of any improvements in their problem-solving abilities.

As part of this study, the STOICHIOCARDS was developed by the researcher as a localized and comprehensive learning tool to address students' difficulties in stoichiometric calculations. Its design featured step-by-step guide cards with procedural methods, differentiated problem sets arranged from beginner to advanced levels, structured challenge cards based on realistic scenarios, and reflective prompts to help learners assess and improve their understanding. These features worked together to create a learning experience that was not only accessible and engaging but also empowering, equipping students with the tools to become active participants in their own learning journey.

2. Materials and method

This study employed an action research framework using a quantitative approach to evaluate the effectiveness of STOICHIOCARDS in enhancing Grade 12 STEM students' proficiency in solving stoichiometric calculations of solutions. Specifically, a pre-experimental one-group pretest–posttest design was adopted, which is considered the simplest experimental structure for assessing change. In this design, a single group of learners was tested before the intervention (pretest), exposed to the treatment (STOICHIOCARDS), and then tested again after the intervention (posttest). The pretest measured students' baseline proficiency, while the posttest assessed improvement after exposure to the intervention. Since no control group was included, observed changes in student performance were attributed to the intervention itself.

The design is represented as follows:

Pretest	→	Treatment or Intervention	→	Posttest
O_1		X_1		O_2

Figure 1 Illustration of the Pre-Experimental One-Group Pretest-Posttest Design

This approach was adapted from Eugelio [11], who utilized the same method in the study KOMIKS: Upskilling Grade 7 Learners on Basic Laboratory Techniques to measure the effectiveness of instructional materials in classroom contexts. Like Eugelio's work, the present study selected this design due to its practicality in real school settings where randomization and control groups are often unfeasible.

The participants of this study were 31 Grade 12 STEM students (16 male and 15 female), ages 17–18, from Section Aguinaldo of Sta. Lucia National High School, Sta. Lucia, Calumpit, Bulacan. The group represented the entire population of Grade 12 STEM students in this section, encompassing learners with diverse sex, attitudes, and socio-economic backgrounds.

A total enumeration sampling method was employed, wherein all members of the defined population were included as participants. This approach was deemed appropriate since the study aimed to assess the effectiveness of STOICHIOCARDS on the entire cohort rather than a subset. Total enumeration ensured that no student was excluded on the basis of prior knowledge or academic performance, thus reducing sampling bias and increasing the representativeness of the findings [12].

STOICHIOCARDS is a comprehensive instructional resource designed to support senior high school learners in mastering stoichiometric calculations of solutions. This innovative guide integrated interactive, scaffolded learning tools with a strong theoretical foundation in constructivist learning theory, cognitive load theory, and experiential learning theory (Kolb).

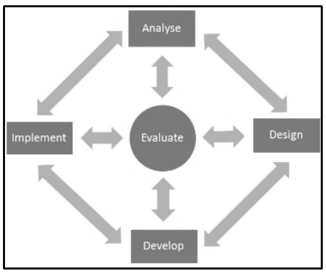

Figure 2 ADDIE Model

As indicated in Figure 2, the development and implementation of STOICHIOCARDS followed the ADDIE model framework, which stands for analysis, design, development, implementation, and evaluation. During the analysis phase, learners' difficulties in stoichiometric problem solving were identified through pre-test diagnostics and teacher observations. In the design phase, instructional strategies aligned with cognitive and constructivist theories were selected and learning outcomes established. The development phase included the creation of Concept, Guide, Reflect, and Challenge Cards, embedding the STAMP and SPICE structured methods. The implementation phase spanned classroom use and alternative learning delivery modes to ensure continuity beyond face-to-face instruction. The evaluation phase involved formative student feedback and summative assessment via pre-test/post-test comparisons along with LRMDS tool validation to refine the intervention.

At the core of STOICHIOCARDS was the belief that students construct knowledge best through meaningful engagement. Through conceptual tools like the Concept Card, learners explored solution concentration concepts in progressive steps—building prior knowledge and linking abstract concepts to real-world contexts such as coffee and juice concentration. The resource provided a structured approach to learning that encouraged students to actively connect new knowledge to their existing understanding.

STOICHIOCARDS was also designed with cognitive load theory in mind. The STAMP and SPICE methods offered structured step-by-step guides to reduce extraneous cognitive load and support germane processing by helping learners focus on schema construction rather than procedural confusion. By organizing problem-solving into clear phases (Spot, Target, Adjust, Match, Plug for concentration problems, and Start, Pick, Identify, Convert, End for stoichiometry), learners avoided cognitive overwhelm and engaged more deeply with the material [13].

Kolb's experiential learning theory provided the foundation for the Challenge Cards. Learners underwent the full cycle of experiential learning—from concrete experience (solving problems) to reflective observation, abstract conceptualization, and active experimentation—allowing ongoing reflection and strategic improvement of problem-solving skills [14].

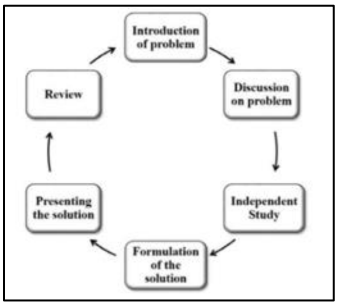

Figure 3 Problem-Based Learning Process Model

In the problem-based learning (PBL) model, as shown in Figure 3, the process begins with a problem on the Stoichiocard. Students proceed through discussion and analysis, working independently or collaboratively to devise solutions. In the independent study phase, they use the Concept, Guide, Reflect, and Challenge Cards and apply STAMP and SPICE strategies to break down complex stoichiometric problems. This scaffolded approach supports critical thinking, self-regulation, and gradual mastery. Reflect prompts foster metacognitive skills, while Challenge Cards of varying difficulty promote differentiated learning.

The STOICHIOCARDS intervention aligns seamlessly with the PBL Process Model, ensuring that students actively engage in problem-solving while receiving the necessary support to master complex stoichiometric concepts. The introduction phase of the PBL model is mirrored in the initial presentation of the stoichiometric problem on the Stoichiocard. This immediately immerses students in the challenge, prompting them to apply their prior knowledge and explore potential solutions.

During the discussion and analysis phase of PBL, students work either independently or in collaborative groups to address the problem. STOICHIOCARDS promotes this by offering a structured learning environment that allows students to engage with the material at their own pace. The resources embedded in the Concept, Guide, and Challenge Cards provide a scaffolded approach to learning, guiding students through each phase of the problem-solving process. Whether working alone or in groups, students are encouraged to apply the STAMP and SPICE methods, which serve as step-by-step guides that break down complex stoichiometric problems into manageable tasks.

The independent study phase of the PBL model, which typically involves researching and exploring solutions, is supported through the self-regulation prompts in the Reflect Card of STOICHIOCARDS. This feature encourages students to monitor their learning progress and reflect on their strategies, reinforcing metacognitive skills. Additionally, the

Challenge Cards present problems at varying levels of difficulty, which caters to differentiated instruction and allows students to build confidence before tackling more complex problems.

Finally, the experiential learning aspect of the PBL process aligns with the Kolb learning cycle embedded in the design of STOICHIOCARDS. By solving progressively challenging problems, students experience Concrete Experience, where they actively work through the problem. Through Reflective Observation and Abstract Conceptualization, they analyze their approaches and refine their problem-solving techniques, which culminate in Active Experimentation, where they apply their learning to new problems. This cycle, supported by the resources in STOICHIOCARDS, fosters deep learning and problem-solving proficiency.

STOICHIOCARDS was more than just a worksheet—it was a learning companion that equipped students to not only compute answers but to understand, reflect, and grow as independent learners in chemistry. Grounded in evidence-based theories and focused on metacognition, STOICHIOCARDS transformed stoichiometry from a challenging topic into a skill that students could master with strategy and confidence. By aligning the intervention with the Problem-Based Learning Process Model, STOICHIOCARDS provided a structured yet flexible approach to mastering stoichiometric calculations, empowering students to engage deeply with content, reflect on their learning, and apply their knowledge to real-world scenarios.

The implementation of the STOICHIOCARDS intervention followed a structured approach, beginning with a pre-test to assess students' prior knowledge of stoichiometry. This was followed by the implementation phase, where students used the STOICHIOCARDS during regular class schedules, or it was implemented at home to extend learning, particularly in cases where face-to-face classes were suspended. In such cases, alternative delivery modes allowed students to use the STOICHIOCARDS independently, ensuring that learning continued even outside the traditional classroom setting. After the intervention, a post-test was administered to evaluate the effectiveness of the STOICHIOCARDS in enhancing students' understanding of stoichiometry. This allowed for a comparison of student performance before and after using the STOICHIOCARDS, providing valuable data to assess its impact on learning outcomes.

The data collection procedure followed three phases: Pre-Implementation, Implementation, and Post-Implementation. In the Pre-Implementation phase, the Action Research Proposal was submitted to the Schools Division of Bulacan and approved by the Research Coordinator and the School Principal. An orientation was conducted for both students and parents, and the STOICHIOCARDS, along with other instruments, were validated by the School Quality Assurance Team (SQAT). During the Implementation phase, informed consent forms were distributed, a pretest was administered to determine students' prior knowledge, and the STOICHIOCARDS intervention was introduced through interactive and task-based activities. At the end of the intervention, a posttest was administered to assess changes in students' proficiency. In the Post-Implementation phase, data from the tests and evaluations were consolidated for analysis to determine the effectiveness of the intervention.

The study adhered to the ethical guidelines of the Department of Education and obtained formal approval from the School Principal and the Schools Division Superintendent before implementation. Informed consent and assent were secured from all participants in compliance with DepEd Memorandum No. 228, s. 2020. To protect participant privacy, identities were kept confidential, responses were properly coded, and data access was limited to the researcher and authorized personnel only. Both digital and hardcopy data were secured following strict protocols, with raw digital data destroyed after analysis and hardcopy materials sealed for safe transfer. These measures ensured that participants' safety, rights, and data privacy were protected throughout the study.

The data were analyzed using both descriptive and inferential statistics. Descriptive statistics, including mean and standard deviation, summarized the SQAT's evaluation of the STOICHIOCARDS in terms of content, format, presentation, and accuracy. Likert scales were used to quantify responses, providing a clear measure of material acceptability. To measure learning gains, a paired samples t-test was applied to the pretest and posttest scores of the students. This test determined whether significant differences existed between their performance before and after the intervention, thereby evaluating the effectiveness of the STOICHIOCARDS in improving proficiency in stoichiometric calculations.

3. Results and discussion

This section presents the findings of the study in a clear and systematic manner. Tables are provided to illustrate the outcomes of the evaluation and statistical analyses conducted.

3.1. Acceptability of the STOICHIOCARDS

Table 1 shows the assessment of the developed STOICHIOCARDS using the LRMDS evaluation tool for printed materials. The School Quality Assurance Team (SQAT), composed of three validators, rated the material in terms of content, format, presentation and organization, and accuracy and up-to-datedness of information.

Table 1 Level of Acceptability of the STOICHIOCARDS based on LRMDS Evaluation Tool for Printed Materials

Factors	Validator 1	Validator 2	Validator 3	Mean Score	Remarks
Factor 1: Content	25	25	25	25.00	PASSED
Factor 2: Format	72	72	72	72.00	PASSED
Factor 3: Presentation and Organization	20	20	20	20.00	PASSED
Factor 4: Accuracy and Up-to-datedness of Information	24	24	24	24.00	PASSED

The results show that the STOICHIOCARDS obtained mean scores in content (25.00) and format (72.00), while presentation and organization received a mean score of 20.00. Accuracy and up-to-datedness of information recorded a mean score of 24.00. All factors were rated as PASSED by the three validators.

Table 1 presents the acceptability of the developed contextualized comics, *STOICHIOCARDS*, as evaluated by the School Quality Assurance Team (SQAT) using the LRMDS evaluation tool. Four areas were assessed: content, format, presentation and organization, and accuracy and up-to-datedness of information. In terms of content, the validators gave a mean score of 25.00 out of a maximum 28.00. Although this score exceeded the passing mark of 21, it did not reach the perfect standard, suggesting room for improvement. The evaluators noted that while scientific accuracy and alignment with curriculum standards were met, the material could be enhanced in fostering the development of desirable values and traits among learners. To address this, integrating character-building contexts or reflective prompts alongside problem-solving activities may strengthen its holistic educational impact.

For format, the material obtained a perfect mean score of 72.00, affirming its well-structured and visually appealing layout. The Mathematics teacher's evaluation highlighted its consistent design, which supports comprehension and learner engagement. Similarly, under accuracy and up-to-datedness, the material achieved a mean of 24.00, reflecting scientifically accurate and curriculum-aligned content. In contrast, presentation and organization, while rated satisfactory with a mean score of 20.00, received the lowest among the four domains. This suggests the need for minor refinements in sequencing and visual flow to further enhance clarity and instructional coherence.

The findings of this study align with those of previous research on General Chemistry modules developed for Grade 12 learners in Bulacan, where materials were also rated "satisfactory" across content, format, presentation, and accuracy [15]. Both studies affirm the importance of teacher and expert validation in ensuring instructional quality and usability. Similar to recommendations in the General Chemistry module evaluation, refinements in content delivery, glossary integration, and improvement of presentation features may further enhance STOICHIOCARDS. Overall, the results indicate that the material is acceptable, pedagogically sound, and ready for classroom use, with minor improvements needed to maximize instructional value and support both cognitive and affective learning outcomes.

3.2. Learners' Pre-assessment and Post-assessment Results

Table 2 Descriptive Statistics of Learners' Pre-assessment and Post-assessment Scores

Assessment Type	N	Minimum	Maximum	Mean	Standard Deviation
Pre-test	31	0	15	8.55	3.880
Post-test	31	14	30	23.71	4.444

Table 2 presents the descriptive statistics of the learners' performance in the pre-assessment and post-assessment. The descriptive statistics reveal that the learners' pre-test scores (N = 31) ranged from 0 to 15, with a mean of 8.55 and a standard deviation of 3.880. In contrast, the post-test scores ranged from 14 to 30, with a higher mean of 23.71 and a standard deviation of 4.444.

The substantial increase in learners' scores from pre-test (M = 8.55, SD = 3.880) to post-test (M = 23.71, SD = 4.444) aligns with findings from Pantao [16], whose study on Team-Based Learning among Filipino Grade 11 STEM learners showed significant improvement in stoichiometric problem-solving performance (control M = 4.06 vs. treatment M = 6.04, p = .001). This underscores the effectiveness of structured, collaborative interventions in enhancing stoichiometric competence. In contrast, Panggabean et al. [17] reported that their Inquiry-Based STEM teaching materials, developed through the ADDIE model, were highly valid (material aspect = 4.42; design = 4.55) and effective primarily in elevating students' low-order and high-order thinking skills (LOTS and HOTS) in stoichiometry, rather than directly producing substantial raw score gains. This indicates an opposite emphasis: while their intervention fostered broader cognitive development, it did not yield the same immediate performance improvements observed in the present study. Nevertheless, both their work and the STOICHIOCARDS intervention share a common foundation in the ADDIE model and a mutual goal of enhancing stoichiometric competency among STEM learners—albeit with differing focal outcomes, one targeting performance metrics and the other targeting cognitive literacy skills.

3.3. Paired t-test on Pre-assessment and Post-assessment Results

Table 3 Paired Samples t-test on Pre-assessment and Post-assessment Scores

Pair	Mean Difference	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference	t-value	df	Sig. (2-tailed)
Pre-test – Post-test	-15.161	4.140	0.744	-16.680 to -13.643	-20.390	30	p < 0.0001.

Table 3 presents the results of the paired samples t-test comparing the pre-assessment and post-assessment scores of learners. The analysis shows a mean difference of -15.161 with a standard deviation of 4.140 and a standard error mean of 0.744. The 95% confidence interval of the difference ranges from -16.680 to -13.643. The computed t-value is -20.390 with 30 degrees of freedom (df). The result is statistically significant with a reported value of p < 0.0001, indicating a highly significant difference between pre-test and post-test scores.

A highly significant result was obtained with a t-value of -20.390, df = 30, and p < 0.0001, indicating a statistically significant difference between the pre-test and post-test scores. These results demonstrate that learners performed considerably better in the post-test compared to the pre-test, reflecting substantial improvement following the instructional intervention.

These findings align with the results of Kimberlin and Yezierski [18], who demonstrated that inquiry-based lessons using particulate-level models had a profound positive effect on students' conceptual understanding of stoichiometry. Similar to the current study, their work highlighted the effectiveness of innovative instructional approaches in addressing persistent misconceptions in stoichiometry. Both sets of findings emphasize that well-structured interventions can significantly enhance student achievement in this area of chemistry learning.

In contrast, Gongden and Bash [19] investigated the use of problem-based learning (PBL) in teaching stoichiometry and also reported significant post-test gains among learners taught with PBL compared to those taught with traditional lecture methods. However, unlike the current study's large mean difference (15.161) with strong statistical significance, their results revealed a more moderate mean gain difference of 19.79 between experimental and control groups, suggesting that while PBL was effective, the magnitude of improvement varied across instructional contexts. This contrast underscores that while diverse pedagogical approaches can enhance student performance in stoichiometry, the degree of improvement may depend on the type of intervention, learner characteristics, and instructional design.

Overall, the results of this study add to the growing body of evidence affirming the effectiveness of alternative instructional strategies in improving learners' achievement in stoichiometry and further highlight the importance of designing validated and teacher-ready interventions to address student difficulties.

The results of this study highlight the significance of STOICHIOCARDS as an innovative instructional tool with practical implications for students, teachers, and educational stakeholders. For students, the intervention simplified complex stoichiometric concepts and improved problem-solving skills, while teachers gained a reliable, engaging strategy to enhance classroom instruction. At the institutional level, school heads and curriculum planners can apply the findings to support curriculum innovation and the DepEd's agenda of fostering critical thinking and active learning. Beyond chemistry, the approach may be adapted to other science subjects, making it a flexible resource for enhancing STEM education. Despite its strong results, the study was limited by its small sample size, single-school setting, and short duration, which may affect the generalizability of the findings. Moreover, the study focused only on two competencies in stoichiometry, leaving other areas of chemistry unexplored. Future research is recommended to validate the effectiveness of STOICHIOCARDS across diverse contexts, grade levels, and subject areas, and to investigate its long-term impact on student achievement and retention. Expanding the intervention's use in larger populations, integrating it with digital platforms, and examining its effect on learner motivation and attitudes toward science would provide a more comprehensive understanding of its educational value and sustainability.

4. Conclusion

- Based on the analysis and interpretation of the data gathered, the following conclusions were drawn:
- The developed STOICHIOCARDS were found to be highly acceptable based on the evaluation of the School Quality Assurance Team (SQAT) using the LRMDS tool. The validators, composed of a Science teacher, an English teacher, and a Mathematics teacher, provided consistently high scores across all four domains: content, format, presentation and organization, and accuracy and up-to-datedness of information. These results affirm the instructional quality, scientific accuracy, visual appeal, and clarity of the material, making it suitable for classroom implementation.
- The descriptive analysis of pre-assessment and post-assessment scores of the Grade 12 STEM learners revealed a significant improvement in their performance after the use of the STOICHIOCARDS. The mean post-test score was substantially higher than the pre-test score suggesting that the learners demonstrated notable gains in their ability to perform concentration and stoichiometric calculations.
- The paired samples t-test results showed a statistically significant difference between the pre-test and post-test scores, with a p-value of 0.000, which is less than the alpha level of 0.05. Therefore, the null hypothesis stating that there is no significant difference in learners' proficiency before and after the intervention was rejected. This confirms that the use of the STOICHIOCARDS had a significant positive effect on the learners' proficiency in solving stoichiometry problems involving solutions.

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