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Enhancing Conceptual Mastery of Green Chemistry Through *Pinakbet*-Themed Crossword Puzzles: An Ethnopedagogical Evaluation

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Abstract

The integration of Green Chemistry into higher education often faces pedagogical challenges due to the abstract nature of its concepts, which frequently leads to a rapid decline in cognitive understanding. Incorporating local wisdoman approach known as ethnopedagogy offers a culturally grounded method to overcome these learning barriers. This study examines the effectiveness of an innovative ethnopedagogical evaluation tool: a crossword puzzle centered on local wisdom, specifically themed around the traditional dish "Pinakbet," in enhancing students' mastery of concepts and their long-term retention. Furthermore, to assess the extent of improvement in student proficiency, an evaluation was conducted using a more diverse range of test items. This follow-up assessment employed a one-group pretest-posttest pre-experimental design and involved 42 undergraduate students from DMMMSU, Philippines.. Data were gathered using a validated 25-item multiple-choice test and analyzed via Shapiro-Will normality test, paired-sample t-test, and Normalized Gain Scores (g). The findings revealed a statistically significant improvement in conceptual mastery ($t(41) = 20.19$, $p < 0.05$), with the cohort achieving a high average gain score ($g = 0.71$). Educators are recommended to adopt culturally responsive gamification as a cognitive anchor and anxiety buffer to translate abstract sustainability principles into durable learning. Future research should apply randomized controlled designs across diverse cultural contexts and subjects to validate long-term retention.

Keywords: Green chemistry, Crossword puzzle, *Pinakbet,* Ethnopedagogical evaluation, Retrieval practice.

Meningkatkan Penguasaan Konsep Kimia Hijau Melalui Teka-Teki Silang Bertema Pinakbet: Sebuah Evaluasi Etnopedagogis

Abstrak

Integrasi Kimia Hijau ke dalam pendidikan tinggi sering kali menghadapi tantangan pedagogis karena konsep-konsepnya yang abstrak, yang menyebabkan penurunan pemahaman kognitif dengan cepat. Integrasi kearifan lokal (etnopedagogi) menawarkan pendekatan berbasis budaya

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untuk mengatasi hambatan pembelajaran tersebut. Studi ini mengevaluasi efektivitas perangkat evaluasi etnopedagogis yang inovatif yaitu teka-teki silang berbasis kearifan lokal dengan tema hidangan tradisional Pinakbet dalam meningkatkan penguasaan konsep dan retensi jangka panjang mahasiswa. Lebih lanjut, untuk mengetahui peningkatan kemampuan mahasiswa, dilakukan evaluasi dengan soal yang lebih bervariasi. Evaluasi lanjutan dilakukan dengan menggunakan desain pra-eksperimental one-group pretest-posttest, penelitian ini melibatkan 42 mahasiswa sarjana dari DMMMSU, Filipina. Data dikumpulkan melalui tes pilihan ganda yang tervalidasi (terdiri dari 25 butir soal) dan dianalisis menggunakan uji normalitas Shapiro-Wilk, uji-t sampel berpasangan (paired-sample t-test), serta skor Normalized Gain (g). Hasil penelitian menunjukkan peningkatan yang signifikan secara statistik dalam penguasaan konsep ($t(41) = 20,19$; $p < 0,05$), dengan kelompok mahasiswa tersebut mencapai skor gain rata-rata yang tinggi ($g = 0,71$). Para pendidik disarankan untuk menerapkan gamifikasi yang responsif secara budaya sebagai jangkar kognitif dan peredam kecemasan, guna mengubah prinsip-prinsip keberlanjutan yang abstrak menjadi pembelajaran yang bertahan lama. Penelitian di masa depan sebaiknya menggunakan desain eksperimen terkontrol secara acak (*randomized controlled design*) dalam berbagai konteks budaya dan mata pelajaran untuk memvalidasi retensi jangka panjang.

Kata kunci : Kimia hijau, Teka-teki silang, Pinakbet, Evaluasi etnopedagogis, Latihan pemanggilan informasi

INTRODUCTION

The integration of Green Chemistry principles into higher education curricula has emerged as a critical global imperative in equipping undergraduate students with the sustainability competencies necessary to address the environmental crises of the twenty-first century. As a core pillar in the transformation of modern industry and science, chemical education no longer merely demands the mastery of technical formulas; rather, it requires the cultivation of an ecological consciousness grounded in the 12 principles of sustainable development (Al-Ismaily et al., 2025). Nevertheless, implementing this curriculum at the university level frequently encounters massive pedagogical challenges. Students' conceptual mastery of Green Chemistry is often impeded by its multidimensional, systemic, and abstract nature (Chen et al., 2020). Undergraduate students are required to simultaneously comprehend the complex interactions between atom economy, waste prevention, the design of safer chemicals, and the utilization of renewable feedstocks (Aubrecht et al., 2019). Consequently, learning outcomes are frequently trapped in superficial memorization, triggering rapid cognitive decay once formal evaluations or final examinations conclude.

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This persistent phenomenon of cognitive attrition indicates that conventional instructional methods traditionally dominated by one way lectures and linear text transfers often fail to establish a "cognitive anchor" strong enough to retain sustainable principles within long-term memory (Balaskas et al, 2025). When information is presented as rigid theoretical doctrine, students tend to experience cognitive overload without being able to internalize the actual essence of the material (Wang et al., 2024). A research assert that the failure of environmental education in higher education generally stems from the curriculum's inability to transform abstract concepts into functional cognitive actions for students (Dillon & Herman, 2023).

This aligns with the Information Processing theory formulated by Atkinson and Shiffrin, which emphasizes that without deep meaning-making or elaborative rehearsal, new information will only reside in the severely limited working memory before eventually being distracted and forgotten (Bouchrika, 2024). Scientific information that is not anchored to a relevant cognitive structure can easily be displaced by other incoming data. This decontextualization is further exacerbated by the dichotomy between formal laboratory science and the realities of daily life. Research by Kwee (2023) also confirms that teaching chemistry in isolation from real world contexts tends to produce superficial, non-permanent understanding, thereby necessitating new instructional strategies capable of structurally reinforcing information retention.

The widening gap between theoretical conceptual mastery and students' ability to recall information (retrieval) is rooted in the lack of contextual relevance in the delivered science material (Hang et al., 2024). Within the realm of cognitive psychology, achieving deep and permanent conceptual mastery depends heavily on the levels of information processing and the degree to which new material connects with the students' existing cognitive structures or prior knowledge (Bergmann, 2022). When new material intersects with a student's empirical experience, the processes of cognitive assimilation and accommodation operate far more effectively.

The Culturally Responsive Teaching (CRT) about transformative solution through ethnic pedagogical evaluation a methodology that deliberately integrates indigenous knowledge into formal science instruction to bridge students' cultural identities with complex academic concepts (Milner, 2022). Through the lens of ethnochemistry, intricate chemical concepts are no longer viewed as foreign products of

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Western thought; instead, they are anchored to the cultural practices, traditions, and domestic techniques deeply ingrained in the local community's daily life, thereby fostering a much stronger intellectual and emotional resonance (Zidny et al., 2020). The theory of cultural border-crossing, posits that science learning becomes far more effective when educators facilitate students' transition from their everyday culture into the sub culture of academic science without creating a cognitive culture shock.

A comprehensive study by Sumarni et al. (2019) demonstrates that ethnochemistry based learning significantly enhances students' critical thinking skills and cognitive mastery compared to conventional, decontextualized methods. By linking chemical phenomena to local cultural objects, students do not merely memorize reactions; rather, they comprehend the underlying philosophy and mechanisms behind those phenomena (Purba *et al*., 2026)

One cultural manifestation rich in ecological values and Green Chemistry principles, yet largely unexplored empirically as a medium for conceptual reinforcement in higher education, is *Pinakbet* (Idul et al., 2025). It’s a legendary traditional dish originating from the Ilocos region of Northern Philippines. Philosophically and practically, this culinary technique emphasizes the utilization of fully renewable feedstocks, energy conservation through layered cooking methods, and high resource efficiency without generating secondary food waste that harms the environment (Cristobal, 2024). Specifically, such practices are linked to principles including the use of renewable feedstocks, waste prevention, energy efficiency, and the employment of safer materials and processes. The utilization of bioactive compounds from plant-based sources via eco-friendly extraction technologies represents one application of green chemistry in food processing (Basile et al., 2024). Furthermore, the development of extraction methods that employ safer solvents—thereby reducing the use of hazardous organic solvents—constitutes a significant aspect of applying green chemistry principles to the processing of natural materials (Ma et al., 2025).

Unfortunately, this rich scientific potential is frequently overlooked and dismissed as a mere domestic cultural activity within formal classrooms, leading to a decoupling of cultural knowledge from modern science literacy (Posselt, 2020). The urgency of this study is reinforced and driven by direct observations and academic interactions conducted by the author during a faculty lecture exchange program at Don

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Mariano Marcos Memorial State University (DMMMSU) North La Union Campus, Philippines. Based on baseline surveys, in-depth interviews, and pedagogical reflections at DMMMSU, an intriguing yet challenging learning paradox was uncovered local students displayed much higher verbal articulation and enthusiasm when chemical reaction variables were analogized with the culinary techniques and material transformations involved in making *Pinakbet* (Bella, 2025). This cultural connectedness creates psychological comfort in learning. Conversely, however, when faced with standardized evaluation instruments, students still experienced significant difficulties in constructing technical definitions, explaining macromolecular mechanisms, and independently and systematically correlating Green Chemistry principles (Aydin et al., 2025). This phenomenon indicates a bottleneck in the encoding stage of information processing, moving from contextual-concrete representations to formal abstract ones. Consequently, an innovative evaluation tool is required to contextualize these scientific principles in a structured, interactive, and engaging manner.

While leveraging cultural heritage contexts has proven effective in boosting students' (Yatim et al., 2025). Initial affective interest and engagement, achieving a lasting grasp of conceptsresistant to memory decay cannot be accomplished solely through the passive delivery of narrative material. Educators cannot simply recount stories about ethnochemistry; active assessment tools are required to reinforce memory traces through challenging yet adaptive information retrieval (active recall) activities. Researchers have recommended various active assessment tools, such as Quizizz (Purba et al., 2021), Kahoot (Haria et al., 2025), and crossword puzzles (Sababalat et al., 2021). In this study, a *Pinakbet* themed crossword puzzle was selected as a strategic gamification tool due to its unique structural characteristics. Crossword puzzles possess the mechanical capacity to trigger neural networks to conduct deep word-concept association searches, stimulate semantic memory, and facilitate the solving of clues within a low-pressure learning environment.

The urgency of this research which focuses on enhancing the mastery of green chemistry concepts through Pinakbet themed crossword puzzles based on an ethnopedagogical evaluation stems from the observation that existing literature has yet to integrate cognitive gamification with local culinary wisdom within a sustainable learning framework. While Sudarmin et al. (2025) incorporated ethnoscience into

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worksheets, and Riswanto et al. (2020) explored gamification for introductory chemistry, neither approach addresses green chemistry principles in a contextual manner or utilizes culture-based crossword puzzles. A similar gap exists in the ethnoscience research by Lestari et al. (2024) and the development of theoretical crossword puzzles by Darmayanti (2022), both of which fail to account for environmental dimensions or the richness of local culinary traditions. Furthermore, although studies on sustainable development by Lestari et al. (2024) address environmental awareness, and work by Afriani & Widodo (2025) focuses on laboratory practical design, these studies remain either too broad in scope or limited to advanced laboratory activities thereby overlooking the potential for a "cultural bridge", such as the philosophy behind the preparation of the vegetable dish Pinakbet. This research specifically addresses this gap by synthesizing thematic crossword puzzles with an ethnopedagogical evaluation, aiming to comprehensively boost students' mastery of key concepts.

This crossword based gamification transforms the intimidating paradigm of testing into a cognitive game that sparks curiosity. The Retrieval Practice theory popularized by Roediger and Karpicke (2006) empirically states that actively retrieving information from memory through regular, low stakes testing such as crossword puzzles is far more effective in building long-term conceptual mastery and enhancing mental flexibility than passive re-studying or re-reading methods. Karpicke (2012) further notes that retrieval practice does not merely test memory capacity; instead, it is an active process that structurally alters and strengthens cognitive pathways within the brain, making that information more accessible in the future. Utilizing crossword puzzles as an ethnopedagogical instrument is expected to revolutionize students' information storage architecture, shifting it from fleeting and fragmented understanding into stable, intact, and well-organized conceptual mastery.

The implementation of *Pinakbet* based ethnochemical crossword puzzles in this study specifically aims to document, analyze, and disseminate how an ethnopedagogical evaluation model can serve as a valid, reliable, and effective tool for conceptual reinforcement in international higher education. By designing clues that creatively bridge modern chemical variables such as pH dynamics in chlorophyll, thermal denaturation of vegetable proteins, biodegradability of organic matter, and atom economy calculations in traditional cooking processes students are indirectly challenged

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to construct far more complex, integrative, and comprehensive cognitive schemas. Based on the background above, the objective of this study is to evaluate the effectiveness of an innovative ethnopedagogical evaluation tool a local wisdom-based crossword puzzle themed around the traditional dish Pinakbet in enhancing students' conceptual mastery and long-term retention.

RESEARCH METHODS

This section explains how the research was conducted. The research methodology includes the type of research, the time and place of the study, the research targets (population and sample for quantitative research, and research subjects for qualitative research); instruments, data collection techniques, and data analysis techniques. This study employed a quantitative pre-experimental approach, specifically utilizing a one-group pretest-posttest design. This design was selected to measure the significant shift and improvement in students' conceptual mastery of Green Chemistry before and after the implementation of the *Pinakbet*-themed crossword puzzles as an ethnopedagogical evaluation tool, as presented in Figure 1.

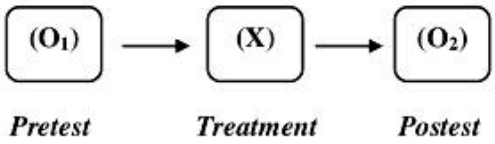


Figure 1. Research Design

Based on the design illustrated in Figure 1, the operational variables of this study are defined through three interrelated operational steps:

O_1 (Pretest) : The initial measurement administered to determine the participants' baseline conceptual mastery of Green Chemistry principles before being exposed to the culturally responsive gamified tool.

X (Treatment) : The independent variable intervention, which involves the implementation of active learning and assessment sessions utilizing *Pinakbet*-themed crossword puzzles. This intervention deliberately embeds local wisdom such as mass efficiency in layered cooking and bioactive compound thermal dynamics into formal chemical concepts.

O2 (Posttest) : The final evaluation conducted after the intervention phase using a parallel assessment instrument to measure the post-treatment cognitive

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level and analyze structural shifts in knowledge retention.

By utilizing a single group, the research directly observed the cognitive transformation and information retention within the exact same cohort, minimizing external cultural variables that might disrupt the ethnochemical analysis. This approach ensures that any statistically significant difference between O_1 and O_2 can be mathematically attributed to the strategic cognitive anchoring provided by the ethnopedagogical crossword puzzles.

The research was conducted at Don Mariano Marcos Memorial State University (DMMMSU) North La Union Campus, Philippines, during a faculty lecture exchange program. The sample was selected using a purposive sampling technique, based on the following specific criteria: 1) Students had formally undertaken or were currently taking Green Chemistry modules; 2) Students possessed an authentic cultural background tied to the Ilocos region, ensuring a native familiarity with the culinary philosophy and practices of *Pinakbet*. The research sample consisted of 42 undergraduate students (N = 42) who took the chemistry course, consisting of 24 students from the College of Arts and Science, Bachelor of Secondary and 18 students from the College of Education, Bachelor of Secondary Education Major in Science.

Two main types of instruments developed and validated are presented in Table 1.

Table 1. Research Instruments

Types of Instrument	**Function**
Treatment Instrument (*Pinakbet*-Themed Crossword Puzzles)	The primary function of this instrument is to serve as an active learning and gamified evaluation medium (X) that facilitates deep information processing. Rather than acting as a passive textbook reading, this instrument functions as a cognitive catalyst designed to stimulate semantic memory through adaptive Retrieval Practice.
The Evaluation Instrument (Conceptual Mastery Test)	The primary function of this instrument is to quantify and measure cognitive shifts by capturing baseline data (O_1) and post-intervention retention (O_2). It is designed to evaluate whether the cultural contextualization successfully translated into formal, abstract academic mastery.

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1) Crossword Puzzles

The crossword puzzle used in this study was designed to transform theoretical green chemistry guidelines into familiar cultural practices. The crossword puzzle design used in the study was created using the Canva application, as shown in Figure 2.

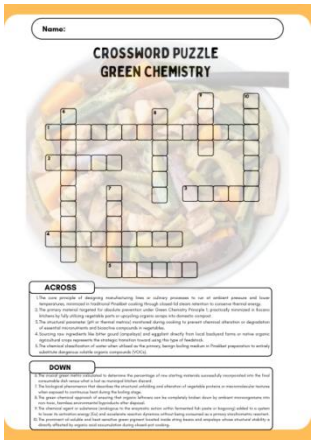


Figure 2. Design of Crossword Puzzle

Functions as a self-correcting mechanism. The intersecting nature of the letters provides immediate, low-stress cognitive feedback, allowing students to realize errors in chemistry terminology independently when letters do not align. gamified ethnopedagogical tool consisting of interconnected crossword clues. The clues structurally bridged modern chemical variables with local culinary wisdom, including resource efficiency, mass conservation, and atom economy calculations (AE) in traditional layered cooking methods.

2) Objective Test

A standardized objective test consisting of 25 multiple-choice questions. The instrument mapped the 12 Principles of Green Chemistry across various cognitive levels of Bloom's Revised Taxonomy (Analyzing-C4, Evaluating-C5, and Creating-C6). Before use, the crossword puzzle and test instrument were validated, were as follows:

1) Validation of the Treatment Instrument focusing on content suitability, instructional design, and cultural readability. Validation was conducted using the assessments of three experts: a chemistry learning material expert, an instructional media expert, and a cultural/ethnopedagogy expert. The percentage of validator agreement was calculated using Aiken's V-index. The instrument items were declared content-valid if the V-value was ≥0.70.
2) Objective validation of the test was conducted using theoretical validation methods.

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The experimental schedule was carried out systematically through three sequential phases over a three period, which is designed in Figure 3.

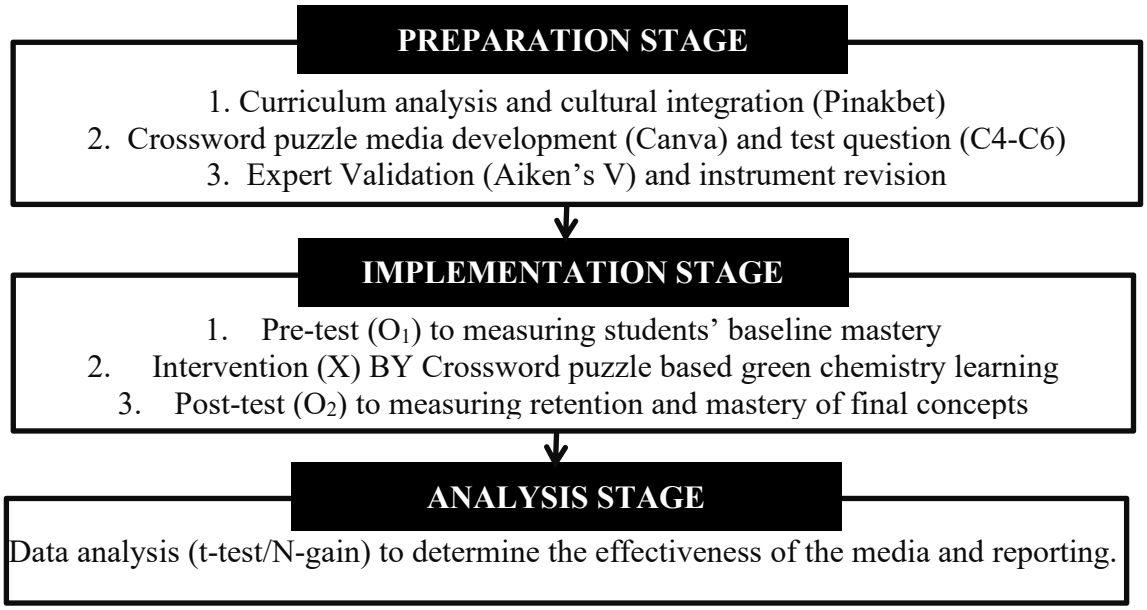


Figure 3. Research Procedure

Quantitative data obtained from the pretest and posttest scores were analyzed statistically using SPSS software through the following mechanisms:

1) Descriptive Statistics, used to calculate the mean, standard deviation, maximum, and minimum scores of both the pretest and posttest.
2) Inferential Statistics (Hypothesis Testing), prior to hypothesis testing, data normality was verified using the Shapiro-Wilk test (appropriate for N < 50). To determine whether the ethnopedagogical crossword puzzle significantly improved conceptual mastery, a Paired Sample t-test was executed at a significance level of alpha = 0.05.
3) Normalized Gain Score (N-Gain), to calculate the actual structural magnitude of the treatment's effectiveness on student learning, the normalized gain score was calculated using the formula:

$$g = \frac{posttest - pretest}{maximum\ score - pretest}$$

The resulting gain value (g) was interpreted based on Hake's criteria: high ($g \geq 0.7$), medium ($0.3\ g < 0.7$), and low ($g < 0.3$).

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RESULTS AND DISCUSSION

The data collected through a valid multiple-choice test instrument. Data on the effectiveness of the local wisdom-based crossword puzzle *Pinakbet* in understanding the concept of green chemistry were obtained from 42 DMMMSU North La Union Campus students. To provide an overview of the characteristics of the respondents and the distribution of the variables studied, the initial step in this analysis was to present descriptive statistics of the data obtained. The data included: study programs, pretest and posttest scores of students, which were grouped in such a way to facilitate interpretation. A summary of the data descriptive presented in Table 1.

Table 1. Data Description

Collage	Sample (N)	Ideal Score	Mean		Range	
			Pretest	Posttest	Pretest	Posttest
Arts and Science	24	100	41.25	81.25	40	50
Education Major in Science	18	100	45.56	86.11	50	30

Based on Table 1, it can be revealed that there was an increase from the pretest scores to the posttest scores for students in classes Arts and Science and Education Major in Science. The difference in the mean pretest and posttest scores of the College of Art and Science class with the College of Education Major in Science and with the entire sample shows an increase in understanding of the concept of green chemistry, as presented in the histogram in Figure 1.

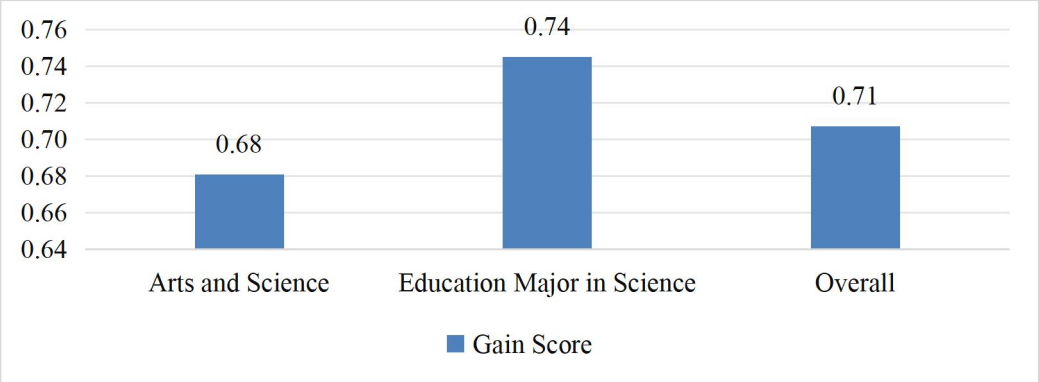


Figure1. The difference in the Mean Pretest And Posttest

Based on figure 1, the score gain of the College of Art and Science class is in the medium category (g=0.68), the score gain of the College of Education Major in Science is in the high category (g=0.74) and the overall sample score gain is in the high category (g=0.71).

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The success of improving understanding of green chemistry concepts, as indicated by the gain scores, needs to be statistically tested to determine its significance. Before conducting a comparative test or hypothesis test to determine the significance of the difference in average pretest and posttest scores, prerequisite data analysis tests were first conducted. The main prerequisite test used was the normality test, which aims to determine whether the learning outcome data from the two sample groups are normally distributed. The results of the normality test analysis using the Shapiro-Wilk method are presented in detail in Table 2.

Table 2. Test of Normality

Statistic	df	Sig.
0.95	42	0.09

Based on Table 2, the results of the normality test informed that the test statistic value was 0.95 with degrees of freedom (df=42). The analysis results show that the significance value (Sig.) obtained was 0.095. Because the significance value is greater than the specified significance level ($p = 0.09 > 0.05$), the null hypothesis (H_0) is accepted. This indicates that the research data is normally distributed. With the fulfillment of this normality assumption, data analysis for hypothesis testing (effectiveness testing) can be continued using parametric statistical methods, namely the paired sample t-test.

After the prerequisite assumptions were met with normally distributed data variance, the analysis proceeded to the hypothesis testing stage to prove the effectiveness of using the *Pinakbet* crossword puzzle media. The statistical test used was a paired sample t-test at a significance level of $\alpha=0.05$. This test aims to determine whether the average difference between the pretest and posttest scores of DMMMSU North La Union Campus students is statistically significant. A summary of the paired t-test calculation results is presented in detail in Table 3.

Table 3. Hypothesis Test Results

Mean	Std. Deviation	t	df	Sig. (2-tailed)
35.24	11.31	20.19	41	0.00

Based on Table 3, the results of the comparative test above, both through the comparison of the t-value ($20.19>2.02$) and the significance value ($0.00<0.05$), H_0 is rejected and H_a is accepted. This indicates a highly significant difference in the average

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values of the studied variables after the treatment. The mean value of 35.24 indicates a significant positive change/increase from the initial to the final condition, with a data dispersion level (standard deviation) of 11.31.

This study demonstrates that integrating local wisdom into game-based learning media can bridge abstract conceptual understanding into a more contextual one. The experimental results empirically demonstrate that the use of the *Pinakbet* crossword puzzle, based on local wisdom, significantly improved students' understanding of green chemistry principles at DMMMSU North La Union Campus. This increase in understanding was consistently reflected across both study programs tested. Students in the Arts and Sciences program and the Education Major in Science program demonstrated a significant increase in scores from pretest to posttest, with normalized gain scores ranging from moderate to high (g=0.68 to g=0.74). This effectiveness indicates that students' cognitive shifts were not simply the result of short-term memorization (rotate learning), but rather a form of conceptual retention formed through meaningful knowledge reconstruction.

The highly significant increase in the t-value ($20.19 > 2.02$; $p < 0.05$) indicates that the intervention using the *Pinakbet* crossword puzzle triggered a strong cognitive shift in students. This phenomenon can be explained through three main dimensions: ethnochemistry, cognitive gamification, and study program-based intrinsic motivation.

The Power of Ethnochemistry as Cognitive Scaffolding

Scientifically, the process of preparing the traditional *Pinakbet* dish is not just a routine domestic activity, but rather a concrete visualization of the mechanisms of analytical chemistry and organic chemistry. The main ingredients, such as bitter melon (bitter melon), eggplant, okra, and long beans, form an organic matrix rich in bioactive compounds, including polyphenols and chlorophyll (Barlongo & Mercado, 2024). When these vegetables are cooked using traditional methods, layered in a clay pot with stable thermal control, the process of protein denaturation and water phase transition occurs efficiently without damaging their nutritional integrity (Heimann, 2025). Furthermore, the use of bagoong (fermented fish paste) acts as a natural flavor catalyst, involving the breakdown of protein macromolecules into free glutamic amino acids through microbial enzymes, until it is ready to be served (Bavisetty et al., 2021), as shown in Figure 2.

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Figure 2. *Pinakbet* Ready to Consume (Macenido, 2023)

This process structure inherently integrates modern scientific principles into the students' local wisdom. Green chemistry is often perceived by students as a collection of abstract psychological principles far removed from the realities of everyday life (Armstrong et al., 2024). Through an ethnochemical approach, the traditional *Pinakbet* dish, familiar to the students' sociocultural background in North La Union, serves as a cognitive scaffolding (Viduya-Galo & Nabua, 2026). As students solve puzzles related to *Pinakbet*'s ingredients and agricultural cycles, incorporating concepts such as renewable raw material use or design for degradation, a natural process of knowledge assimilation occurs. For example, the concept of waste reduction (waste prevention) is illustrated through the efficient use of fresh, local vegetables without long supply chains, which inherently minimizes the carbon footprint and synthetic waste packaging (Abbas *et al*, 2025). Students no longer see green chemistry as a Western industrial doctrine, but rather as an extension of sustainability practices already practiced by their local communities (Zuin *et al*., 2021)

From a cognitive psychological perspective, the effectiveness of this medium can be explained through David Ausubel's Meaningful Learning Theory (Bryce and Blown, 2024). According to Ausubel, new learning will only be meaningful if the information can be linked to concepts already present in the students' cognitive structures (Widada, 2016). *Pinakbet*, as part of students' daily culinary and agrarian identities, acts as a facilitator of advanced life skills (Hafalia-Yackel, 2025). When this indigenous knowledge structure is activated, students' working memory capacity is no longer burdened by unfamiliar terms, but instead focuses on mapping chemical concepts onto a mature cultural foundation (Purba and Sormin, 2025). This aligns with Lev Vygotsky's *Zone of Proximal Development (ZPD)* concept (Hamedi *et al.*, 2025). Through natural assimilation of knowledge, this crossword puzzle contextualizes the 12 Principles of Green Chemistry proposed by Anastas and Warner (1998) into local socio-

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cultural practices, as in Figure 3.

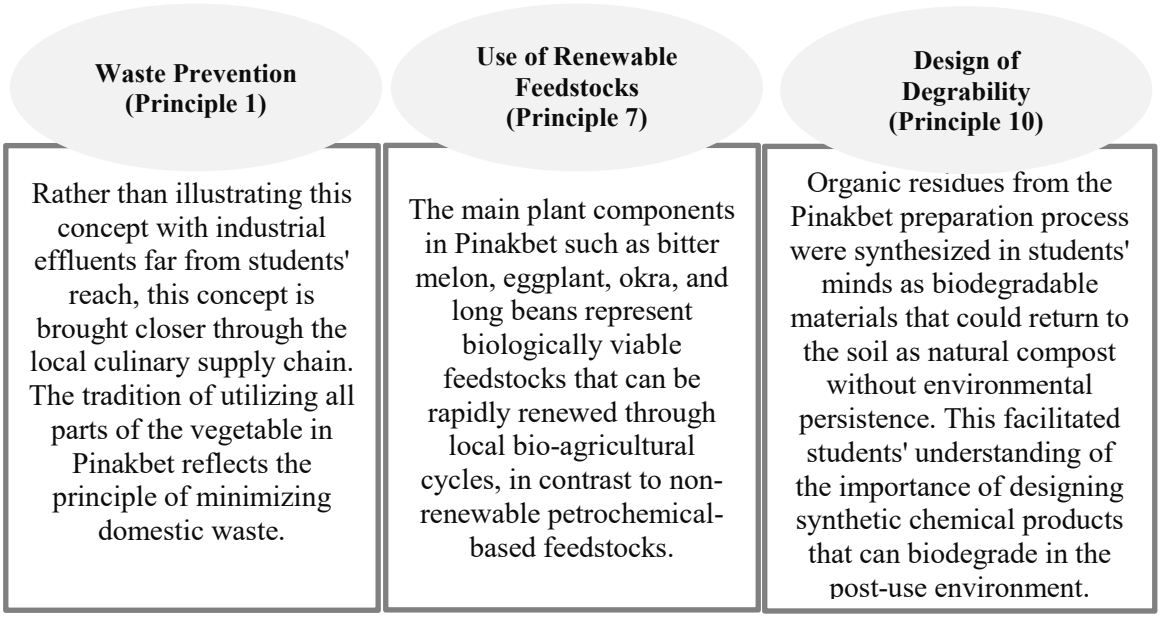


Figure 3. Integration of Green Chemistry Principles into Local Cultural Practices of *Pinakbet* Preparation

Based on Figure 3, the *Pinakbet* crossword puzzle acts as an external scaffold that encourages students to move from their zone of actual ability (knowing the components of local cuisine) to their zone of potential ability (understanding the green chemical mechanisms behind those components) (Yuriev et al., (2016). The success of this conceptualization reinforces Glen Aikenhead's "*Cultural Border-Crossing*" theory. Aikenhead (1996) stated that science learning often requires students to travel across cultural boundaries from their home world into the school science subculture. For most students, this transition feels unfamiliar and intimidating. The ethnochemical approach in the *Pinakbet* medium acts as a cultural tour guide, softening these boundaries, allowing for a smooth cognitive transition (border-crossing). These findings consistently support previous studies that emphasize the importance of culturally responsive science pedagogy in modern chemistry education, as presented in Table 4.

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Table 4. Comparison and Relevance of the Present Research Findings with Previous Ethnochemical Studies

Researcher (s) & Year	Focus of Relevant Findings	Relevance to the Present Research Findings
Sjostrom et al. (2016)	Suggests that chemistry education should be systematically oriented toward socio-ecological issues and contextual sustainability (*socio-ecological chemistry*).	The *Pinakbet* crossword puzzle successfully translates abstract global sustainability principles into immediate, localized socio-cultural actions for the students.
Mahaffy (2015)	Introduces the *Tetrahedral Chemistry Education* framework, which integrates a human and cultural dimension into Johnstone's traditional macro-micro-symbolic chemistry triangle.	The integration of local Filipino culinary wisdom heavily solidifies this human dimension, directly reflected in the massive surge of the empirical t-value (20.19).
Viduya-Galo & Nabua (2026)	Found that embedding ethno-chemistry into the science curriculum radically enhances students' scientific literacy and environmental awareness.	The high normalized gain score (g = 0.71) achieved by the DMMMSU sample firmly confirms that the ethno-chemical approach fosters deep conceptual mastery rather than rote memorization.

Based on Table 4, through this synthesis of theory and empirical evidence, it can be concluded that the power of ethnochemistry in the *Pinakbet* medium lies in its ability to deconstruct the Eurocentric or industrial-centric biases within the principles of green chemistry. Students ultimately realize that green chemistry is not a foreign, modern Western industrial doctrine, but rather a scientific crystallization of sustainability practices that have been passed down through generations within their own local communities. This aligns with the perspectives of several researchers who argue that green chemistry should not be viewed merely as a modern scientific concept, but also as a scientific approach that recognizes, explicates, and reinforces ecological practices that have evolved within local indigenous wisdom (Habiyaremye & Korina, 2021; Zidny & Eilks, 2022).

Crossword Puzzle Gamification and Memory Retention

Pedagogically, the superiority of the *Pinakbet* crossword puzzle lies in its gamification architecture, which structurally forces students to transform from passive consumers of information into active learning. Unlike exposure to conventional linear text, which tends to trigger the illusion of competence, solving crossword puzzles

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demands a high level of cognitive engagement (Beanland and Moore, 2023). Exploring the effectiveness of this medium in revolutionizing student understanding can be analyzed through three theoretical lenses retrieval practice architecture, cognitive load optimization, and affective anxiety management (Baksi, 2025).

The process of filling in the blanks in a crossword puzzle requires students to engage in retrieval practice an active process of recalling information and conceptual schemas from long-term memory to solve the available clues. The statistically significant leap, demonstrated by the t-value of 20.19 ($p<0.05$), is closely related to the Testing Effect theory (Asay et al., 2022). They confirmed that self-testing memory using a specific instrument resulted in far superior long-term memory retention compared to repeated restudying (Binks, 2018). When students read crossword clues addressing green chemistry concepts, their brains were forced to reconstruct neural pathways. The small obstacles encountered while searching for the correct word within the available boxes created what Bjork and Kroll (2015) call *Desirable Difficulties.* These controlled difficulties actually strengthened memory traces and increased students' cognitive flexibility in transferring that knowledge to new contexts, such as when faced with a posttest. The nomenclature and principles in green chemistry, such as atom economy, catalysis, or inherently safer chemistry for accident prevention, have a high level of linguistic and conceptual complexity. These characteristics inherently burden students' limited working memory. From the perspective of Cognitive Load Theory (Sweller, 2020), the TTS media "Pinakbet" acts as a tool to reduce extraneous cognitive load and optimize German cognitive load.

Crossword puzzles break down the complexity of green chemistry terms through a "*chunking*" mechanism, which draws on George Miller's (1956) theory of memory capacity. Rather than presenting dense and tedious textual definitions, crossword puzzles present information in discrete chunks (Khaewratana, 2022). The filled-in letters of the intersecting words act as implicit cues that guide working memory to identify the next concept without expending excessive mental energy (Matkin, 2025). By reducing extraneous load, this interactive visual format allows students to focus their working memory on building new sustainable chemistry schemas (Ndruru *et al*., 2026).

An important aspect that is often overlooked in higher level science learning is the emotional dimension of students (Pranata, 2025). Chemistry often triggers affective

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barriers in the form of chemistry anxiety. According to *Attentional Control Theory* developed by Eysenck et al. (2007), anxiety consumes the processing capacity of the central executive system in working memory. As a result, anxious students lack the cognitive space to process complex material (Hawes & Arya, 2023). The recreational effects and playfulness of the "Pinakbet" crossword puzzle gamification function as an anxiety buffer in the classroom (Yuriev *et al*., 2016). When the learning environment shifts to a challenging yet enjoyable word game, students' stress levels decrease drastically (Papadimitriou & Virvou, 2025). This phenomenon resonates strongly with Stephen Krashen's Affective Filter Hypothesis. Reducing anxiety lowers the affective filter, easing information flow to the brain, as shown in Figure 4.

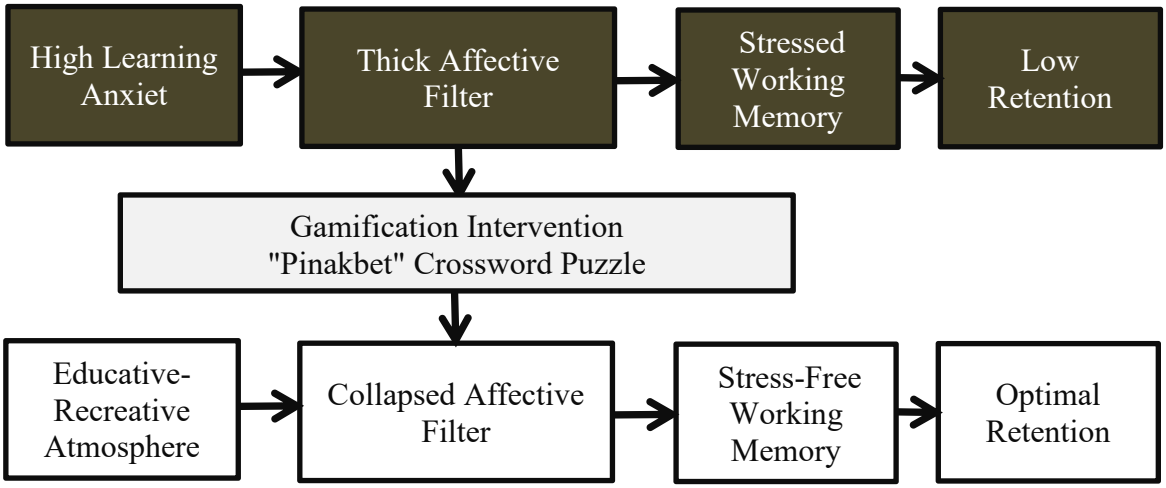


Figure 4. The Mechanism of "Pinakbet" Crossword Puzzle Gamification as an Anxiety Buffer in Chemistry Learning

Based on Figure 4, it can be shown that the findings of this study strengthen the empirical evidence base regarding the effectiveness of word-based gamification in science education. These results align with a study by Buckley and Doyle (2016), which found that gamification can substantially boost student engagement by increasing intrinsic motivation. In the specific context of chemistry learning, the high overall gain score (g=0.71) in this study supports the report by Sababalat *et al.* (2021), who found that regular crossword puzzle use positively correlated with improved scientific vocabulary acquisition and final exam scores. By integrating crossword puzzles as a retrieval tool and a means of reducing psychological stress, the "Pinakbet" media demonstrates that superior academic performance need not be achieved through monotonous drill methods, but rather through instructional design that adapts to the

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natural workings of the human brain.

The successful use of the "Pinakbet" crossword puzzle has significant implications both theoretically and practically. For chemistry learning, this research successfully challenges the dogma that green chemistry instruction must rely on expensive modern laboratory infrastructure, offering an alternative strategy in the form of a rich, inclusive, and low-cost sociocultural based "contextual laboratory" (low cost chemistry). This is supported by research from Pearson (2020), which indicates that chemistry crossword puzzles are a learning tool that is easy to prepare, low-cost, and capable of fostering active student engagement in learning chemistry concepts. Annur et al. (2021), who developed simple teaching aids based on green chemistry concepts as an alternative practical activity to overcome limited laboratory facilities. Meanwhile, for the curriculum and educators, these findings provide a strong recommendation particularly at institutions like DMMMSU to deconstruct the curriculum and shift from rigid standard text materials to the integration of local narratives into modern science. Through this transformative step, educators can not only significantly boost students' academic achievement but also help preserve their cultural identity amidst the currents of global modernization to achieve eco-cultural sustainability.

CONCLUSION

Based on the ethnopedagogical evaluation conducted at DMMMSU North La Union Campus, it is concluded that the implementation of the *Pinakbet* themed crossword puzzle effectively resolves pedagogical bottlenecks in undergraduate Green Chemistry education. The quantitative analysis confirmed a highly significant cognitive shift and high learning gains from the baseline to the final post-treatment condition across the cohort. Empirically, the integration of local culinary wisdom acted as a potent cognitive scaffold and a smooth cultural guide, accelerating the assimilation of complex chemical concepts into existing indigenous knowledge structures. Furthermore, the game based retrieval practice mechanics successfully optimized students' working memory capacity by flattening their affective filters and reducing chemistry anxiety. Ultimately, this study demonstrates that embedding indigenous cultural heritage into active assessment instruments offers a valid, inclusive, and low cost instructional strategy to foster stable, long term global sustainability competencies without relying on expensive modern laboratory infrastructures.

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DECLARATION:

Phenomenon: Jurnal Pendidikan MIPA was selected as the target journal for the publication of our paper because it strives to promote the implementation of high-quality mathematics and science education at all educational levels—an objective that aligns with the vision and scope of this internationally reputable journal. We confirm that all authors have approved the manuscript for publication in your journal.

Availability of Data and Materials: The data supporting the study was classified according to the institutions' authorities; therefore, the participants only agreed to participate in the study based on anonymity, and a confidentiality agreement was reached. The data can therefore not be divulged to any third party without official permission granted from the institutions which can either be accepted or declined.

Competing interests: The authors declare that they have no conflicting interests in the publication of the paper in your journal.

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Generative AI Statement: Generative AI tools, were used for limited language editing and phrasing improvements. The research design, data collection, analysis, interpretation, and scholarly conclusions were developed and verified by the authors, who take full responsibility for the content of the manuscript.

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