



Cognitive Metamorphosis: Optimizing Chemistry Understanding Through Numeration-Visual Integrated Methods For 3T Students

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Abstrak– Penelitian ini mengkaji efektivitas metode pembelajaran integratif numerasi-visual dalam meningkatkan pemahaman mahasiswa terhadap kesetimbangan kimia. Subjek penelitian terdiri dari 42 mahasiswa dari Lanny Jaya dan Nduga, Papua. Metode eksperimen kuasi dengan pre-test dan post-test digunakan untuk mengukur peningkatan pemahaman. Hasil penelitian menunjukkan peningkatan signifikan dari rata-rata skor pre-test 45,2 menjadi 78,6 pada post-test ($t(41) = 12,35$, $p < 0,001$). Respons mahasiswa terhadap metode ini positif, dengan skor rata-rata 4,3 dari 5 berdasarkan angket skala Likert. Beberapa kendala yang dihadapi adalah keterbatasan akses teknologi dan kesulitan awal dalam memahami grafik. Secara keseluruhan, metode ini efektif dalam meningkatkan pemahaman konsep kesetimbangan kimia dan dapat diterapkan di daerah dengan keterbatasan sumber belajar.

Kata Kunci: Kesetimbangan Kimia, Integrasi Visual-Numerasi, Mahasiswa 3T

Abstract– This study examines the effectiveness of the numeracy-visual integrative learning method in improving students' understanding of chemical equilibrium. The subjects of the study consisted of 42 students from Lanny Jaya and Nduga, Papua. A quasi-experimental method with pre-test and post-test was used to measure the increase in understanding. The results showed a significant increase from an average pre-test score of 45.2 to 78.6 on the post-test ($t(41) = 12.35$, $p < 0.001$). Students' responses to this method were positive, with an average score of 4.3 out of 5 based on a Likert scale questionnaire. Some of the obstacles faced were limited access to technology and initial difficulties in understanding graphs. Overall, this method is effective in improving understanding of the concept of chemical equilibrium and can be applied in areas with limited learning resources.

Keywords: Chemical Equilibrium, Numeracy-Visual Integration, 3T Students

1. INTRODUCTION

Understanding concepts in chemistry learning is a fundamental aspect that determines the success of the learning process, especially at the higher education level (M. iman Sari *et al.*, 2018). Chemistry, as a science that bridges macroscopic and microscopic phenomena, requires students to be able to think abstractly, logically, and systematically (Nirmalasari *et al.*, 2024). The numeracy-visual integrative method is a learning approach that combines numerical abilities (numeracy) with visual representation in conveying abstract concepts (Munahefi *et al.*, 2023). In the context of chemistry, this approach includes the use of quantitative data, graphs, molecular diagrams, three-dimensional models, and systematic visualization of chemical reaction dynamics (Sinaga *et al.*, 2023). The main goal is to strengthen students' cognitive reasoning power by facilitating the connection between numbers and images as media for representing knowledge. This approach is in line with the cognitive constructivist theory which emphasizes the importance of active involvement of students in building knowledge through various forms of mutually reinforcing mental representations (Eviota & Liangco, 2020). Numeracy in chemistry learning refers to students' ability to interpret, analyze and process numerical information related to chemical phenomena (Eliza *et al.*, 2021). For example, in understanding the ideal gas law, students must be able to relate the relationship between pressure, volume, temperature, and number of moles mathematically and symbolically (M.A Yohanita Nirmalasari *et al.*, 2022). On the other hand, visualization allows students to associate symbolic representations with images of molecular structures, reaction directions, and visualizations of energy changes in a chemical reaction (R. T. Sari *et al.*, 2023). The combination of both can strengthen cognitive schemes and reduce the gap between mastery of theory and practice, especially for students from 3T areas who tend to have limited access to comprehensive learning media. Previous studies have shown that multiple representation-based approaches can improve understanding of science concepts, including chemistry. For example, a study conducted by Ainsworth (2006) stated that the integration of multiple representations including numerical and visual can improve conceptual understanding and problem-solving abilities of students. Furthermore, Mayer and Moreno (2002) in their theory of multimedia learning emphasize that learning will be more effective if information is presented simultaneously in verbal and visual forms, because it will maximize short-term memory work and increase information retention. Research by Kozma and Russell (1997) also supports this view by showing that the use of visual simulations in learning chemical reactions can improve students' analytical thinking skills.

When viewed from other studies, a study by Harjono *et al.* (2019) showed that visual numeracy-based learning in the context of virtual experiments improves students' critical and conceptual thinking skills in understanding reaction rates and chemical equilibrium. Meanwhile, research by Ningsih and Suyanto (2021) found that a visual-numerical



approach in learning stoichiometry can improve students' ability to understand the molar ratio and mass of reactants and products. Finally, research by Amalia and Suradika (2020) proved that the integration of visual numeracy in thermochemistry learning had a significant impact on mastery of the concept of enthalpy and changes in the energy of the reactant system. From these findings, it appears that the visual-numeracy approach has great potential in shaping students' cognitive metamorphosis, especially in understanding abstract and complex chemical materials. Chemical materials that are very relevant to the application of the visual-numeracy integrative method include stoichiometry, thermochemistry, chemical kinetics, chemical equilibrium, and atomic structure. In stoichiometry material, students are required to be able to convert mass to moles, determine the ratio of reactants and products, and visualize the relationship between reaction components in the form of flow diagrams or tables (Djarwo, 2020). In thermochemistry, understanding concepts such as enthalpy, heat, and energy changes requires numerical skills as well as visualization of energy curves. Chemical kinetics material really requires the ability to process experimental data into concentration-time graphs, so that students' understanding of reaction mechanisms and the factors that influence them becomes deeper. Meanwhile, in chemical equilibrium, understanding the graph of the relationship between substance concentration and time, as well as forward-backward reactions, is crucial and more effective if accompanied by visual representation (Wati & Novita, 2021). Atomic structure also requires numerical representation in calculating the number of subatomic particles and visualizing orbitals and electron configurations (Damayanti & Priatmoko, 2023).

3T students often face challenges in terms of learning approaches that are not fully contextual and adaptive to their needs. In many cases, the chemistry teaching approach applied is still one-way, focused on memorizing concepts, and minimal use of visual and numerical-based learning media. In fact, the characteristics of chemical materials are very complex and require understanding across levels of representation, namely macroscopic (direct observation), microscopic (molecular and particle structures), and symbolic (reaction formulas and equations). When one of these levels is not fully connected, students tend to experience misconceptions or just memorize without truly understanding the essence of the chemical concept. Therefore, a transformation is needed in the pedagogical approach, which not only transfers knowledge, but also forms critical thinking skills, mental visualization, and numeracy skills simultaneously. The numeracy-visual integrative method is presented as an alternative to bridge the gap. This approach views that understanding of chemical concepts can be strengthened through the integration of three important components, namely: first, numeracy mastery, namely the ability to read and interpret numerical data and apply it in a chemical context; second, visualization, namely the ability to convert symbolic information into visual representations such as diagrams, graphs, and molecular models; and third, the integration of both in one complete and continuous learning strategy. Students are not only invited to calculate, but also to visualize the meaning of the numbers being processed. Conversely, they also do not only see images or simulations, but are invited to explore the quantitative meaning of the visualized phenomena.

For example, in thermochemistry learning, students often have difficulty understanding the relationship between energy changes and reaction processes. With the numeracy-visual integrative approach, students are invited to analyze the graph of enthalpy changes against the reaction path, while calculating the amount of heat released or absorbed. Energy level diagrams can be combined with data tables of temperature changes, mass, and heat capacity to strengthen conceptual understanding. This combination not only improves students' numeracy skills but also encourages them to build a mental picture of the process that is occurring in a chemical reaction. The implementation of this approach cannot be separated from the support of cognitive theories that have been developed. One relevant theory is the dual coding theory by Paivio (1986), which states that information presented in verbal and visual forms will be easier to remember and process in long-term memory. In the context of chemistry learning, this theory is very relevant because chemical concepts require a connection between symbols, numbers, and molecular visualizations. In addition, Sweller (1988) through cognitive load theory also emphasizes the importance of managing cognitive load in the learning process. When material is presented in only one format, such as text or numbers, the cognitive load becomes high and can hinder the process of internalizing concepts. However, if information is presented in multiple formats (for example, numbers complemented by graphs and visualizations), then cognitive load can be better managed so that understanding is more easily formed.

The numeracy-visual integrative learning model is also in line with the multiple representation approach in science learning. Multiple representation is the use of two or more ways to convey the same information, such as text, numbers, graphs, tables, and images. According to Ainsworth (1999), multiple representations have three main functions in learning: (1) to elaborate and strengthen understanding, (2) to compare and contrast information, and (3) to compensate for the weaknesses of each representation. In this context, the use of numerical data without visualization can limit students' conceptual imagination, while visualization without numeracy can obscure the quantitative aspects of the concept. Therefore, combining the two can form a more complete and in-depth understanding. Recent research by Wahyuni, Nurhayati, and Subekti (2022) shows that numerical and visual integration in digital-based atomic structure learning stimulates the development of students' spatial skills, which have been a challenge in understanding orbitals and molecular shapes. In this study, students not only learned electron configurations through the periodic table and numerical notation, but also through visual modeling based on augmented reality (AR). As a result, there was a significant increase in concept mastery and long-term retention of the material. A similar study by Mahmudi and Yuliana (2021) in the West Sulawesi region also showed that the integration of heat versus time graphs in thermochemistry experiments was able to improve students' predictive ability regarding the direction and magnitude of



enthalpy changes, which were previously often misunderstood because they were only studied through mathematical formulas alone.

The relationship between technology and visual-numeracy approach provides a more dynamic and responsive educational environment according to student needs. The integration of technology in education aims to enhance learning outcomes and equip students to confront the problems of the Society 5.0 era, which demands critical and creative thinking abilities (Saputra *et al.*, 2023; Satiti *et al.*, 2022). The implementation of this method does not have to be based on sophisticated technology. In conditions with minimal technology, the visual-numeracy approach can be implemented conventionally through the use of data cards, graph paper, simple measuring instruments, and manual visualization with diagrams or physical models. Teachers or lecturers can design Student Activity Sheets (SAS) based on multiple representations, where students are asked to compile experimental observation data, create graphs, explain the visual meaning of the graphs, and relate them to relevant chemical theories. This strategy not only forms understanding, but also trains accuracy, logical reasoning, and scientific communication skills. The cognitive metamorphosis referred to in the title of this journal is not just a change in the way of thinking from not knowing to knowing, but a fundamental transformation in the way students process, compile, and internalize chemical knowledge. This change is evident in the shift in students' learning approaches from initially passive, reactive, and rote to active, reflective, and integrated. Students who experience cognitive metamorphosis will show characteristics such as being able to map relationships between concepts, build mental models that are in accordance with microscopic reality, and make quantitative and qualitative predictions of the chemical phenomena being studied. This transformation certainly does not happen instantly, but rather through a learning process that is designed holistically and sustainably.

Furthermore, chemistry learning that is oriented towards the integration of numeracy and visualization has the potential to improve students' scientific literacy. In a global context, scientific literacy includes not only mastery of scientific concepts, but also the ability to use scientific knowledge to solve real-world problems, make decisions, and understand scientific issues in society. By equipping 3T students through the numeracy-visual method, the scientific literacy process can be carried out more meaningfully, because they not only learn "about science", but also "how to think scientifically". The implementation of the numeracy-visual integrative approach in chemistry learning not only has practical implications in improving conceptual understanding, but also provides theoretical contributions to the development of chemical education, especially in the realm of cognition-based learning design. Theoretically, this approach broadens the scope of constructivism theory by emphasizing that the construction of meaning occurs not only through verbal and symbolic experiences, but also through the simultaneous interaction between complementary numerical data and visual images. Within the framework of Dual Coding Theory (Paivio, 1986), the presence of information in numerical and visual forms allows the activation of two different representational systems in the brain, which then increases the storage capacity of information and the ability to connect concepts.

In the context of education in 3T areas, technology plays a very important role in improving the quality of learning. Students in 3T areas often face significant challenges, including limited access to educational resources, inadequate facilities, and restrictions in technology use (Vania *et al.*, 2021). Many 3T areas face inadequate infrastructure problems, such as slow or non-existent internet networks, and limited access to technological devices like computers or smartphones, which are necessary for modern learning (Gumilang *et al.*, 2022; Lellola *et al.*, 2023; Koesnandar, 2013).

Furthermore, students in the 3T region have great potential for the progress of their own regions. They are agents of change who will one day return to their respective communities to become educators, local researchers, extension workers, or community activists. If they are not equipped with strong scientific literacy competencies and understanding of chemistry, their contribution to sustainable development in their regions will be hampered. Therefore, the development of a learning model that can bridge this gap is a necessity. The integrative numeracy-visual method can be one concrete solution, because this approach can be developed flexibly, adaptively to local resources, and has been proven to improve students' chemical cognition based on previous empirical findings. This research is very urgent to be carried out. First, because there is a real cognitive gap in the understanding of chemistry among 3T students. Second, because the integrative numeracy-visual approach offers a pedagogical solution that is based on strong theory, practically implemented, and flexible in limited conditions. Third, because there are not many studies that specifically explore the influence of this approach on the cognitive development of chemistry students in the 3T area, so this study also contributes to filling the gap in the literature that is still open. Finally, because the results of this study are expected to not only provide theoretical and practical contributions, but also become advocacy material for educational policy makers to pay special attention to learning strategies based on the specific needs of students in the 3T area. Thus, this study is not only relevant, but also strategic in encouraging the transformation of chemistry learning in the 3T area. The expected cognitive metamorphosis does not only occur at the individual level, but also in the broader educational ecosystem: changing the perspective on learning chemistry, redesigning more contextual and meaningful learning experiences, and raising local potential as part of national pedagogical innovation.

2. METHOD



This research method uses a mixed methods approach with a quasi-experimental design and a qualitative phenomenological study. The quantitative approach is used to measure the effectiveness of the numeracy-visual integrative method, while the qualitative approach aims to explore students' experiences and challenges in understanding chemical concepts. The research subjects consisted of 42 students from Lanny Jaya (20 students) and Nduga (22 students), Papua, which are 3T areas with limited access to technology-based learning media. Data collection was carried out through several instruments. The initial test (pre-test) and final test (post-test) were used to measure the increase in understanding of chemical concepts after the application of the numeracy-visual integrative method. In-depth interviews were conducted to explore students' experiences, obstacles, and perceptions of this learning approach. In addition, a Likert scale questionnaire was given to determine students' responses to the methods applied. Classroom observations were also conducted to record student involvement in learning and how they process the material numerically and visually.

This study focuses on the material of chemical equilibrium, which is one of the fundamental concepts in chemistry learning and is often a challenge for students. This material includes the laws of chemical equilibrium, Le Chatelier's principle, equilibrium constants (K_c and K_p), and factors that affect equilibrium shifts. The numeracy-visual integrative method is applied using graphs of changes in concentration versus time, forward and backward reaction diagrams, and visual simulations that illustrate the dynamics of the equilibrium system. During the learning process, observations were made to observe the patterns of student interactions and how they responded to the material given. After the intervention, students took a post-test to see how far their understanding had improved. Interviews and questionnaires were given as a reflection of the effectiveness of the methods used. Data obtained from the test were analyzed using statistical tests to see significant differences between the pre-test and post-test results, while data from interviews and observations were analyzed qualitatively with a phenomenological approach to understand students' experiences in the learning process.

3. RESULT AND DISCUSSION

3.1 Analysis of Pre-Test and Post-Test Results

This study used a pre-test and post-test to measure the increase in students' understanding of the concept of chemical equilibrium after the application of the numeracy-visual integrative learning method. The pre-test results showed that students' initial understanding was relatively low with an average score of 45.2 on a scale of 0-100. After the learning intervention, the average post-test score increased significantly to 78.6. This increase was analyzed using a paired t-test, resulting in a value of $t(41) = 12.35$, $p < 0.001$, indicating a significant difference between the pre-test and post-test. In more detail, the results of the pre-test and post-test can be seen in Table 1.

Table 1. Descriptive Statistics of Pre-Test and Post-Test Results

Parameter	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	t-value	p-value
Final Score	45,2 ± 12,5	78,6 ± 10,8	12,35	< 0,001

The distribution of scores also showed a consistent increase. In the pre-test, only 10% of students scored above 70, while in the post-test, this number increased to 82%. These results indicate that the integrative numeracy-visual method is able to significantly improve students' understanding.

3.2 Analysis Based on Regional Groups

This study also compared the results between students from Lanny Jaya and Nduga. The results of the analysis showed that before the intervention, students from both regions had almost the same average pre-test scores, which were 44.8 for Lanny Jaya students and 45.6 for Nduga students. However, after the learning, students from Nduga experienced an increase in their average score of 77.2, while students from Lanny Jaya increased to 79.9. The ANOVA test showed that there was no significant difference between the two groups in increasing understanding ($F(1,40) = 0.89$, $p = 0.35$), so this method was effectively applied in both regions evenly. A more detailed comparison of the pre-test and post-test results based on the student's regional area can be seen in Table 2.

Table 2. Comparison of Pre-Test and Post-Test Results Based on Region

Place of Origin	Pre-Test (Mean ± SD)	Post-Test (Mean ± SD)	Improvement
Lanny Jaya	44,8 ± 12,7	79,9 ± 9,8	35,1
Nduga	45,6 ± 12,3	77,2 ± 11,5	31,6

3.3 Effectiveness of Numeracy-Visual Integrative Method



The results of the study indicate that the numeracy-visual integrative approach can significantly improve students' understanding of the concept of chemical equilibrium. This is in line with previous research by Mayer & Moreno (2002), which states that visual and numerical representations combined in learning can improve information absorption and long-term memory. In this study, the methods used include various representations, such as graphs of changes in concentration versus time, forward and backward reaction diagrams, and interactive simulations. Students who initially had difficulty understanding the relationship between equilibrium factors, after this learning can more easily interpret the concept using the help of numerical visualization.

In addition, this method allows students to build connections between the concept of equilibrium and its real-life applications, such as in the chemical, pharmaceutical, and environmental industries. Students who initially had difficulty in understanding the relationship between equilibrium factors, after this learning can more easily interpret the concept with the help of numerical visualization. Previous studies have also shown that a visual-based approach can improve long-term retention and reduce misconceptions in understanding abstract concepts in chemistry. Furthermore, analysis of student responses shows that this method makes learning more interesting and interactive than conventional lecture methods. The high post-test scores achieved by students indicate that the integration of numeracy and visualization can help improve their analytical skills in solving chemical equilibrium problems. Therefore, this method can be recommended as the main approach in teaching abstract concepts in chemistry, especially for students from areas with limited access to conventional learning resources.

3.4 Student Response to Learning Methods

To measure students' responses to this learning method, a Likert scale questionnaire was given with a range of 1-5 (1 = strongly disagree, 5 = strongly agree). The results of the analysis showed that students gave a positive response to this method with an average score of 4.3. The results of the student response questionnaire in more detail can be seen in Table 3.

Table 3. Results of Student Response Questionnaire

Statement	Mean ± SD
This method helped me understand the concept of chemical equilibrium better	4,5 ± 0,7
Graphical visualization makes it easier for me to understand the dynamics of equilibrium	4,4 ± 0,6
The use of simulations helped improve my understanding	4,2 ± 0,8
I feel more confident in working on questions related to equilibrium	4,1 ± 0,9
This method is more interesting compared to the conventional lecture method	4,3 ± 0,8

Most students stated that this method was more interesting than the conventional lecture method and helped them understand the material better. This supports the Dual Coding Theory by Paivio (1986), which states that combining verbal and visual representations can improve students' understanding and memory.

3.5 Obstacles in Learning

Although the results showed high effectiveness, there were several obstacles faced during the implementation of this method. The interview results showed that 28.6% of students had difficulty interpreting graphs at the beginning of learning. In addition, 35.7% of students stated that access to technology-based learning tools was still limited in their area, which made it difficult for them to adapt to this learning. Difficulty in understanding technical language was also one of the biggest obstacles. The obstacles faced by students in more detail can be seen in Table 4.

Table 4. Obstacles Faced by Students

Obstacle Details	Percentage (%)
Difficulty understanding graphs at the beginning of learning	28,6%
Limited access to technological devices	35,7%
Lack of previous experience in visual-based learning	21%
Language barriers in understanding technical terms	42%

From the interviews conducted, several students suggested that lecturers provide more practice in reading graphs and provide teaching materials in the form of printed modules as an alternative for students who have difficulty accessing simulations digitally. Based on the findings of this study, the integrative numeracy-visual method has proven



effective in improving students' understanding of chemical equilibrium. However, to further increase its effectiveness, several recommendations are given, namely: (1) providing learning modules in printed and digital forms so that students can access the material more flexibly, (2) increasing training in reading and interpreting graphs as part of a learning strategy, and (3) developing lightweight application-based simulations that can be accessed by students with technological limitations.

4. CONCLUSION

The results of this study indicate that the numeracy-visual integrative learning method can significantly improve students' understanding of the concept of chemical equilibrium, with an increase in scores from 45.2 to 78.6 after the learning intervention. Further analysis showed that students from both regions, Lanny Jaya and Nduga, experienced similar improvements. In addition, the results of the questionnaire showed that students responded positively to this method, despite obstacles in access to technology and interpretation of graphs. By overcoming these obstacles through a more adaptive approach, this method can be further optimized for application in chemistry learning in the 3T area.

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