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The Effectiveness of Puzzle-Based Teaching Strategy in Improving Biomolecule Understanding

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Abstract — Biomolecules have been known to be one of the most abstract and conceptually challenging subjects in science education, leading to low student mastery. The paper evaluated the effectiveness of Puzzle-Based Teaching (PBT) instruction in enhancing the knowledge of biomolecules in a group of Bachelor of Secondary Education (BSEd) students in Science. The quasi-experimental pretest- posttest control group design was used that involved twenty (20) second year students in experimental group (n=10) and control group (n=10). An equivalent test is a 40-item multiple choice achievement test which was validated before and after the intervention. The experimental group was provided with instructional activities based on puzzles with collaborative problem- solving tasks, and control group was instructed through traditional methods based on lectures. The analysis of data was performed by means of paired-samples and independent-samples t-tests, and Analysis of Covariance (ANCOVA) was used to ensure that baseline differences were controlled. Even though improvement in posttest scores was observed in both groups, there was no statistically significant difference in the mean gain scores, $t = 0.42926$, $p = .67$. The results of ANCOVA also demonstrated that the treatment effect was not statistical when it was corrected by pretest scores, $F(1,17) = 1.64$, $p = .217$, with a small effect size ($\eta^2 = .088$). These results indicate that although slightly numerically significant gains in puzzle-based teaching were seen, this did not result in statistically significant gains in biomolecule achievement. Future studies ought to focus on larger sample sizes, increased duration of intervention and enhanced scaffolding of instructions to better assess capability of puzzle-based techniques in science education.

Keywords: Puzzle-Based Teaching Strategy, Biomolecule Understanding, Science Education, Student Engagement, Biochemistry

I. INTRODUCTION

Teaching complex scientific concepts in an engaging and accessible way remains a challenge in modern education, particularly in the field of biochemistry. Biomolecules are key elements in the living organisms, but they are abstract in structure and interact with each other at the molecular level, which is why this study may present a challenge to the students. Conventional instructional practices are helpful, but not necessarily effective in helping fix the disconnect between complicated scientific material and learner cognition or involvement (Gierdowski et al., 2020). Consequently, new instructional approaches are being considered more and more often in order to enhance more profound knowledge and engagement in learning science.

The innovative solution is Puzzle-Based Teaching (PBT), which is an instructional model which involves puzzles with the aim of building critical thinking, problem solving, and analytical reasoning. Michalewicz and Michalewicz (2008) claim that puzzle based learning will expose students to the principle of structured problem solving by the way of the activities that are entertaining and thought provoking. It has already been revealed that puzzle-based approach can improve the learning process in different fields. Indicatively, Molina (2023) and Mendoza (2022) reported positive effects of puzzles on problem-solving skills, group learning, whereas Adedoja and Fakokunda (2015) suggested better retention and academic achievements with the help of computer-based puzzles. Equally, the study in the Philippine setting shows that interactive and collaborative approaches may deliver a high level of achievement in science and student involvement (Rogayan and Tabiolo, 2020).

Although extensive literature bases are building up on the use of puzzle-based learning in mathematics, language, and other subjects, the empirical research on whether this method is efficient in the learning of complicated biological entities, specifically, biomolecules, is scarce. This became particularly apparent in the undergraduate education of the sciences, such as in the Bachelor of Secondary Education major in Science. Puzzle-based strategies have the potential to offer an interactive and meaningful visualization of relationships by the student in addition to enhancing conceptual learning and knowledge retention due to the abstract nature of biomolecular concepts.

Thus, the purpose of the study is to investigate how effective puzzle-based teaching methods can be in enhancing the knowledge of Biomolecules among Bachelor of Secondary Education (BSEd) students of Science at Jose Rizal Memorial State University. Through the evaluation of this instruction teaching method, the research aims at contributing to the advancement of student oriented and innovative methods of teaching that improve learning and performance in science.

Literature Review

Teaching, Puzzle-based instruction as a new method of teaching has become a bridging conception of teaching practices that involve critical thinking, interest and problem solving, as an instructional technique in different fields of knowledge. A number of researches have been carried out in the Philippine setting to indicate the efficacy of puzzle-based interventions to enhance academic performance. Concerning the example, Layoc (2024) discovered that jigsaw puzzle tasks contributed tremendously to language learning skills besides promoting teamwork and leadership among high school students. In a similar way, Rosas (2023) showed significant increases in algebraic ability among first year students of BSEd Mathematics on puzzle-based learning exercises. Other works also show that puzzle-based strategies encourage a collaborative learning process and conceptual learning in mathematics classes (Madrid & Bartolome, 2023) and can be efficiently implemented even in early-year education to enhance the foundational abilities of recognizing and multiplying numbers (Davao Oriental State University Cateel Campus, 2025; Calunacon Elementary School, 2025a).

The effectiveness of puzzle-based learning as a student-centered instructional approach is also supported by the international research. According to Umoru et al. (2016) and Oriji and Oguguo (2020), puzzle-based activities increased students engagement and motivation in science courses. Falkner et al. (2014) and Nicholson and Cable (2021) also stressed the idea that puzzles enhance critical thinking and imagination along with active learning in different fields. Other more recent STEM Learning articles suggest that puzzle-based learning develops better logical reasoning, computational abilities, and problem-solving in learners (Pan and Liu, 2022; Moon and Park, 2025). All these results indicate that puzzle-based instructional learning has the potential to convert the traditional learning classes into interactive learning opportunities that promote a higher level of thinking.

Engagement of students is very essential in science learning especially when handling complex and abstract concepts. Research indicates that learners become the most active and tenacious when the methods of instruction are interactive and relevant and learner centered. In line with Belisario and Paglinawan (2025), interest in science inquiry among students plays a major role in determining whether they will participate in the classroom activities. Equally, Madjos (2024) and Lakshmi (2024) documented that instruction in science in meaningful and contextualized way improves the motivation and the willingness of students to engage in challenging activities. Inquiry-based learning and collaborative learning are also active learning strategies that lead to better conceptual knowledge and to sticking to the science classes (Haak et al., 2020; Villalba et al., 2024). Moreover, technology-based learning tools offer a student a chance to visualize complicated scientific phenomena and engage in working with abstract notions in various other ways (Kizilcec and Schneider, 2020).

Despite these advancements, teaching biomolecules remains particularly challenging due to the abstract and microscopic nature of molecular biology concepts. Tibell and Rundgren (2010) explain that students often struggle to visualize molecular structures and biochemical interactions because these processes occur beyond everyday human experience. Misconceptions about molecular structures and biochemical processes further complicate learning (Fuchs et al., 2021; Suparman et al., 2024). Researchers therefore recommend the use of multiple representations and interactive learning strategies to support students in developing accurate mental models of biomolecular structures (Herman et al., 2020; Zhao & Chen, 2021). Supporting this view, Cajocon, Pontioso, and Tamayo (2024) reported that modern technology enhances students' understanding by providing broader access to diverse learning resources and interactive tools such as laptops and tablets, which improve communication and task efficiency among students at Jose Rizal Memorial State University. However, their findings also indicate that excessive screen time may lead to distractions and weakened interpersonal relationships, potentially limiting deeper comprehension if not balanced with traditional instructional approaches. Nevertheless, instructional constraints such as limited resources, insufficient laboratory facilities, and inadequate teaching strategies continue to hinder effective biomolecule instruction (Magtulis, 2025; Bautista & Arevalo, 2020).

Overall, existing literature demonstrates that puzzle-based teaching strategies can improve engagement, critical thinking, and academic performance across different subjects. However, empirical studies examining the application of puzzle-based instruction in teaching biomolecules remain limited, particularly in undergraduate science education. Addressing this gap is essential to determine whether puzzle-based strategies can enhance students' conceptual understanding of biomolecules and support more interactive and meaningful science learning.

II. METHODOLOGY

The research design used in this study was a quasi-experimental research design to study the effectiveness of puzzle-based teaching in enhancing better understanding of biomolecules among students. The design had been two participant groups; the first group was the experimental one where the participants were instructed through puzzle-based activities and control group where the participants were instructed by using the other more traditional methods of instruction. Quasi-experimental designs are broadly applicable in the educational research because they enable researchers to assess causality connection in natural classroom/setting and take practical constraints into consideration non-random group assignment (Gopalan et al., 2020; Osmanović Zajić and Maksimović, 2022).

The effectiveness of the intervention was to be evaluated by giving the pre-tests and the post-tests to both the groups to determine the level of their knowledge and understanding of the biomolecules. The pre-test was used to determine the level of understanding before training, whereas the post-test was done to determine the level of learning after the training intervention. Testing procedures and implementations of the trainings were conducted in a standardized way to keep the results realistic and valid. By such a design, the study managed to draw a comparison between the learning outcomes of the two groups and also assess the effectiveness of puzzle-based teaching as one of the methods of teaching complex scientific topics.

Research Environment

The research was carried out at Jose Rizal Memorial State University (JRMSU) Dipolog Campus among twenty (20) graduate students in Science under the Bachelor of Secondary Education (BSEd) degree program. This institution was chosen due to the fact that JRMSU is a place where future educators of science are trained, since the emphasis of its curriculum is on inquiry-based teaching and laboratory-supported education. Within the framework of the present study, biomolecules are being taught in foundational courses in life science that students are expected to learn about abstract molecular structures and processes, which are areas that students typically have conceptual challenges. This rendered JRMSU a suitable environment to look at whether a puzzle-based instructional methodology could be able to raise the level of student involvement, problem-solving approach, and conceptual attainment of biomolecules. Availability of functional science laboratories, classroom arrangements and institutional assistance of academic research combined further offered a favorable setting with which to carry out and assess this teaching invention.

Respondents

The participants of the study consisted of twenty (20) Bachelor of Secondary Education (BSED) science students enrolled at Jose Rizal Memorial State University – Dipolog Campus. These second-year students were divided into two groups: ten (10) students in the control group and ten (10) students in the experimental group. The assignment of participants to each group was based on their previous chemistry grades to ensure comparable academic ability. This grouping aimed to provide a fair basis for determining the effectiveness of the puzzle-based teaching strategy in improving biomolecule understanding.

Instrument

The primary instrument was a researcher-made multiple-choice knowledge test designed to measure students' understanding of biomolecules before and after the intervention. The test was developed using a Table of Specifications (TOS) to ensure alignment with the learning objectives on carbohydrates, lipids, proteins, and nucleic acids. Reliability was established through pilot testing and statistical analysis. The intervention utilized four researcher-designed puzzle activities integrated into the lesson plans: a matching puzzle for carbohydrates, a crossword puzzle for lipids, a jigsaw puzzle for proteins, and sequence-based and rebus puzzles for nucleic acids, each aligned with specific learning objectives to enhance conceptual understanding and cognitive skills.

Procedure

Permission to conduct the study was first obtained from the school administration and the identified participants prior to data collection. A researcher-made pretest was administered to both the control and experimental groups to determine their initial level of understanding of biomolecules. After the pretest, the control group received conventional instruction through lectures, guided discussions, and textbook-based learning, while the experimental group was taught using a puzzle-based teaching strategy integrated into the prepared lesson plans. The intervention was implemented across four instructional sessions, each focusing on a specific biomolecule topic: carbohydrates, lipids, proteins, and nucleic acids. During the sessions, the experimental group engaged in structured puzzle-based activities designed to reinforce learning objectives, including matching puzzles for carbohydrates, crossword puzzles for lipids, jigsaw puzzles for proteins, and sequence-based puzzles for nucleic acids. Each instructional session followed a structured format consisting of topic introduction, guided discussion, activity engagement, practice exercises, and lesson summarization to ensure consistent delivery of content across groups. Meanwhile, the control group covered the same topics within the same timeframe using traditional instructional strategies without puzzle activities. After completing the four instructional sessions, the same researcher-made knowledge test was administered as a posttest to both groups to measure learning gains. The pretest and posttest scores were collected, tabulated, and prepared for statistical analysis. A paired-samples t-test was used to determine significant differences between the pretest and posttest scores within each group, while an independent-samples t-test compared the posttest scores of the control and experimental groups. Additionally, analysis of covariance (ANCOVA) was conducted to compare posttest scores while controlling for pretest scores as a covariate. Ethical standards were observed throughout the study, including voluntary participation, confidentiality of responses, and secure storage of research data.

Ethical Consideration

Ethical standards were strictly observed throughout the study. Permission to conduct the research was obtained from the school administration and the participants prior to data collection. Students were informed about the purpose of the study, and their participation was voluntary, with the option to withdraw at any time without penalty. Confidentiality and anonymity of all responses were ensured during data collection, analysis, and reporting. All collected data were securely stored in a restricted-access digital file to protect participants' privacy and maintain data integrity.

III. RESULTS AND DISCUSSION

TABLE 1
PRETEST PERFORMANCE OF CONTROL GROUP AND EXPERIMENTAL

Dependent Variable: Pre-Test Score

0=control,1 = experimental	*Mean*	*Std. Deviation*	*N*
0	25.60	4.671	10
1	25.10	4.095	10
Total	25.35	4.283	20

The results in Table 1 show that the control group obtained a slightly higher mean pretest score (M = 25.60, SD = 4.67) than the experimental group (M = 25.10, SD = 4.10). However, the minimal difference indicates that both groups had nearly similar levels of prior knowledge before the intervention. This suggests that the students entered the study with comparable baseline competencies, supporting the initial equivalence of groups commonly required in quasi-experimental designs (Álvarez-Nava et al., 2024; Kim & Park, 2022). Establishing comparable pretest scores is important because it allows any observed differences in posttest performance to be more confidently attributed to the instructional intervention rather than to pre-existing differences among participants (Creswell & Creswell, 2021). Moreover, diagnostic assessments such as pretests are essential in science education because they help identify students' prior knowledge and misconceptions, which influence conceptual learning and instructional effectiveness (Kaltakci-Gurel et al., 2025; Tatar et al., 2025). Research also indicates that identifying misconceptions early allows educators to design more targeted instructional strategies that support conceptual development (Adnyana et al., 2025; Kurniawati et al., 2024). Consistent with methodological recommendations for quasi-experimental pretest–posttest studies, the comparable pretest scores observed in this study provide a reliable baseline for evaluating the impact of the instructional intervention (Kandola et al., 2024; Regmi, 2024). Thus, the established pretest equivalence strengthens the validity of subsequent analyses examining the effectiveness of the puzzle-based teaching strategy in improving students' understanding of biomolecules (Creswell & Creswell, 2021; Saputro et al., 2023).

TABLE 2
TEST OF DIFFERENCE BETWEEN THE PRETEST AND POSTTEST OF THE STUDENTS IN THE EXPERIMENTAL GROUP IN TERMS OF TEST

Dependent Variable: Post Test Score

Source	*SS*	*df*	*MS*	*F*	*p*	η^2_p	Cohen's d	*Interpretation*
Corrected Model	19.024a	2	9.512	2.130	.149		.200	
Intercept	443.368	1	443.368	99.271	.000	.854		
pretest	10.574	1	10.574	2.368	.142	.122		
treatment	7.328	1	7.328	1.641	.217	.088	0.19	Small
Error	75.926	17	4.466					
Total	22473.000	20						
Corrected Total	94.950	19						

a. R Squared = .200 (Adjusted R Squared = .106)

An analysis of covariance (ANCOVA) was conducted to compare posttest scores while controlling for pretest performance. The overall model was not significant, $F(2, 17) = 2.130$, $p = .149$, explaining 20% of the variance in posttest scores ($R^2 = .200$; Adjusted $R^2 = .106$). Neither the covariate (pretest scores), $F(1, 17) = 2.368$, $p = .142$, $\eta^2 = .122$, nor the treatment condition, $F(1, 17) = 1.641$, $p = .217$, $\eta^2 = .088$, showed statistical significance. These findings indicate that baseline knowledge did not significantly predict post-intervention performance and that the puzzle-based instructional strategy did not produce a statistically significant improvement in students' posttest scores. The effect size for gain scores (Cohen's d = 0.19) was small, indicating minimal practical impact and aligning with the non-significant inferential results. Together, these findings suggest that the intervention had limited measurable influence on students' biomolecule achievement.

These results contrast with studies reporting significant improvements from puzzle-based, game-enhanced, and interactive instructional strategies in science education (Assapun et al., 2023; Bawazeer et al., 2022; Dabbous et al., 2023; Debrenti & Moraru, 2024; Idika & Oluwaseyi, 2024; Tosunöz & Karacabay, 2023). Such studies emphasize that well-designed and adequately implemented active-learning approaches can enhance achievement, engagement, and retention. However, recent literature also highlights that intervention outcomes are highly dependent on factors such as instructional design quality, alignment with learning objectives, teacher facilitation, scaffolding, learner readiness, and duration of implementation (Moon et al., 2024; Pan et al., 2022; Sun & Hsu, 2023). When interventions are brief, insufficiently scaffolded, or implemented with limited intensity, effects may be modest or inconsistent (Debrenti & Moraru, 2024; Debrenti, 2024). In the present study, the small sample size may have reduced statistical power, potentially limiting the detection of significant differences (Assapun et al., 2023; Dabbous et al., 2023). Additionally, the comparable pretest scores and possible ceiling effects may have constrained observable gains (Bawazeer et al., 2022). Future research should consider larger samples, longer intervention periods, enhanced instructional scaffolding, and comprehensive analytical designs to more accurately determine the effectiveness of puzzle-based strategies in improving student learning outcomes (Idika & Oluwaseyi, 2024; Sun & Hsu, 2023).

TABLE 3
TEST OF DIFFERENCE ON THE MEAN GAINS BETWEEN THE CONTROL AND EXPERIMENTAL GROUP

Group	Mean Gain	*SD*	*t*	*p*
Control	8.50	4.38	0.42926	.67 ^{ns}
Experimental	7.70	3.95		

The comparison of mean gain scores showed that the control group obtained a slightly higher mean gain (M = 8.50, SD = 4.38) than the experimental group (M = 7.70, SD = 3.95). However, the computed t-value (t = 0.43, p = .67) indicates that the difference between the two groups was not statistically significant at the 0.05 level. This result suggests that the puzzle-based instructional intervention did not produce a measurable improvement in learning outcomes compared with the traditional instructional approach used in the control group. Since the p-value exceeded the significance threshold, the null hypothesis stating that there is no significant difference between the mean gains of the two groups was accepted.

Similar findings have been reported in educational research where interventions show numerical differences but fail to reach statistical significance. Non-significant p-values are common in intervention studies due to small effect sizes, limited statistical power, or design constraints (Edelsbrunner, 2024; Bulus & Koyuncu, 2021). Studies in science education also report comparable performance between innovative and traditional instructional formats when instructional quality and assessment demands are similar (Adams et al., 2016; Jensen et al., 2015, as cited in Adams et al., 2016). However, other studies have shown significant improvements when interventions are highly interactive or technology-enhanced. For instance, augmented reality and game-based learning environments have demonstrated significant gains in student achievement when activities are sustained and cognitively engaging (Alotaibi, 2024; Cai et al., 2025; Chang et al., 2022; Dabbous et al., 2023; Ivgin, 2024).

The moderate variability within groups and the relatively small sample size may also have limited the detection of significant differences, as high within-group variability and limited statistical power can mask potential treatment effects (Althubaiti, 2022; Bulus & Koyuncu, 2021; Besekar et al., 2024; Memon et al., 2020). Additionally, external factors such as learner motivation, prior knowledge, and contextual variables may influence learning outcomes in quasi-experimental classroom studies (Capili, 2024; Lumampao, 2023). Overall, the findings suggest that the implemented instructional strategy did not yield a statistically significant advantage over traditional instruction, highlighting the need for stronger instructional design, longer intervention duration, and larger sample sizes in future research to better evaluate the effectiveness of puzzle-based learning approaches (Chang et al., 2022; Alotaibi, 2024).

IV. DISCUSSION

The aim of the current study was to establish the efficiency of puzzle-based instruction strategy in improving student knowledge of biomolecules. Both the pretest and posttest and statistical test results indicated that even though both the control and experimental groups had shown learning gains, the puzzle-based strategy did not provide statistically significant difference with the traditional instruction. Similar patterns have been observed in some puzzle- and game-based learning implementations when exposure is short or the design is introductory rather than intensive (Arnold et al., 2024). These findings emphasize how the instructional design, exposure duration, and the complexity of the material contribute to the successful use of innovative approaches to the learning of science (Kaynak et al., 2023).

The pretest results confirmed that the control and experimental groups had nearly identical baseline competencies, indicating comparable prior knowledge and supporting the internal validity of the quasi-experimental design (Arnold, 2024; Eren & Bektas, 2025). Posttest results showed that both groups improved, although the control group obtained a slightly higher mean score ($M = 34.10$) than the experimental group ($M = 32.80$). The experimental group also demonstrated greater variability, suggesting that puzzle-based activities may benefit some learners more than others depending on engagement, readiness, or familiarity with innovative tasks (Kaynak, 2023; Kalkan, 2022; Shasliani, 2024; Da Cruz, 2023).

Further analysis using ANCOVA indicated that neither pretest scores nor the treatment significantly affected posttest performance, and the small effect size ($d = 0.19$) suggested minimal practical impact. These findings are consistent with research showing that short or insufficiently scaffolded puzzle activities may mainly support review and engagement rather than immediate achievement gains (Arnold, 2024; Edelsbrunner, 2023; Partovi & Razavi, 2019). Additionally, small sample sizes and moderate variability may reduce statistical power and mask potential effects (Bulus & Koyuncu, 2021; Memon et al., 2020). Overall, while puzzle-based strategies may enhance motivation and participation, their effectiveness may depend on longer implementation, stronger scaffolding, and integration with multimodal or technology-supported learning resources (Abdjul et al., 2024; Tosunöz & Karacabay, 2023; Kaynak, 2023).

V. CONCLUSION

Based on the findings study indicate that although teaching methods involving puzzles have a pedagogical potential, they can be less effective to promote the levels of knowledge of students on biomolecules when used in a short time span or without appropriate scaffolding. Teachers must understand that these strategies can foster engagement, active learning, and differentiated learning despite the situation of small improvements in standardized test scores. Thus, it seems that puzzle-based interventions can be the most effective when incorporated into the larger teaching structures, like problem-based or inquiry-based learning, supported by multimodal material, and lasting more than a year to support the establishment of the intricate information. This means that puzzles can be viewed as an adjunct to, but not a stand-alone method, particularly to abstract scientific material especially by teachers, to enhance meaningful conceptual learning and long-term student engagement.

In addition, some contextual, and learner-related issues could have contributed to the study results. These comprise prior knowledge of students in the areas of chemistry and biology, cognitive preparedness of abstract molecular concepts, learning styles and intrinsic interest in subjects of science. The extent of teacher facilitation, instructions, time, and correspondence of puzzle activities to assessment measures might also have influenced the extent of quantifiable change. Also, the classroom setting, the nature of the peer collaboration, and the quality and difficulty of the puzzle materials themselves may lead to the difference in learning gains. The future applications can be even more successful in case these variables are controlled in a systematic way, in case the formative feedback rides the intervention, and in case the longitudinal exposure will enable students to build and consolidate biomolecular concepts.

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