Heuristic and Algorithmic Approaches to Algebraic Problem Solving in Secondary Schools in Bayelsa State, Nigeria

Owonuwa Seun, Gamage Tubona*

Mathematical Sciences Education Programme (MSEP) National Mathematical Centre, Abuja, Nigeria

DOI: https://doi.org/10.51584/IJRIAS.2026.11070079

Received: 16 July 2026; Accepted: 21 July 2026; Published: 04 August 2026

ABSTRACT

This study is a comparative experimental study of heuristic and algorithmic approaches to algebraic problem solving in secondary schools in Bayelsa State. The study discussed the problems of algebraic reasoning and some over-reliance on memorizing procedures that have been raised in the teaching of mathematics in secondary schools. This study in particular examined the achievement and retention differences between students taught using heuristic versus algorithmic methods. Quasi experimental pretest, posttest and retention test design was used with 240 students of Senior Secondary School Two from six public secondary schools. The data were obtained from the results of Algebraic Problem Solving Achievement Test, which was validated by mathematics education and educational measurement experts. Data was analyzed using Mean, SD and ANCOVA. Results showed that the students taught using heuristic instructional approach obtained the higher post test scores and had higher retention ability as compared to students taught by algorithmic approaches. It was concluded from the study that the heuristic instruction facilitated deep concept understanding, strategic thinking and retention in algebraic problem solving more than the conventional procedural instruction. The study suggested that there is a need to incorporate heuristic instructional approach in secondary school mathematics teaching and learning to enhance students' analytical ability and performance in solving mathematical problem.

Keywords: Heuristic Approach, Algorithmic Approach, Algebraic, Problem-Solving, Secondary Schools.

INTRODUCTION

Mathematics education has been at the core of scientific progress, technological innovation, and national development for the reason that mathematics serves as a logical framework for learners to process relationships between quantities and to solve real-life problems. Algebra plays a crucial role in school mathematics, as higher mathematics, abstract thinking and analytical problem solving are based on algebra. The importance of it notwithstanding, underachievement in algebraic problem solving has remained a feature of secondary school education in Nigeria with some students in public secondary schools exhibiting low level performance in algebraic problem solving, characterized by procedural memorization and lack of conceptualization. Numerous reports from national examination bodies have highlighted that many students at secondary school find it particularly challenging to translate verbal statements of a mathematical situation into a symbolic representation, manipulate algebraic expressions with accuracy and use logical strategies when solving unfamiliar problems. These deficits have led to an interest among researchers in the efficacy of traditional teaching methods in mathematics classrooms. This challenge of algebraic problem solving has prompted a shift in the focus of research on instruction toward strategies that can facilitate deep learning of algebraic reasoning and not merely memorization of algebraic methods. Current mathematics education research has focused on the importance of meaningful learning, which takes place when the learner is able to create pathways for solving problems by using strategic thinking, pattern identification, and reflective reasoning. Under these circumstances, heuristic approaches have garnered significant attention due to the fact that they stimulate exploratory thinking, flexible reasoning, visualization and strategic discovery in problem solving processes (Kaitera & Harmoinen, 2022). The Heuristic Instruction (also known as problem-solving instruction) emphasizes mathematical structures, relationships between variables and alternative pathways for finding solutions instead of repeating memorized procedures. The heuristics'

educational significance is related to their ability to deepen thinking and conceptual understanding in mathematical reasoning.

Historically, the notion of heuristics has been linked to problem solving techniques that aim to make complex decision making easier by making smart approximations and guided reasoning. Heuristic models are very popular in the computational sciences, optimization theory, and artificial intelligence, but have a strong theoretical relationship to education problem solving processes. It has been observed that heuristic and meta-heuristic methods enhance solution generation in complex and uncertain environments in the past few years (Rokbani et al., 2021; Braik et al., 2020; Wang et al., 2021). Heuristic systems have been utilized to produce adaptable and flexible answers to calculation issues that cannot be easily addressed by hardcoded methodologies, in engineering optimization (Alsattar et al., 2020; Dereli & Köker, 2020). Together, these studies provide further evidence for the heuristic reasoning and its role in adaptability, creativity and strategic flexibility in solving of difficult tasks. Algorithmic, on the other hand, focuses on the definite process of logical and procedural actions that will be used to generate precise and predictable results. Traditional algorithmic teaching in mathematics classes puts emphasis on procedural fluency, repetitive exercises and rules for computing. This method has traditionally been adopted in secondary school mathematics classes in order to give students a framework of how to reach the right answers. However, with this current trend of using the algorithmic approach to teaching mathematics, there are also growing concerns that students are not acquiring mathematical knowledge in an environment where they can transfer the knowledge to novel situations, nor acquiring the skills to solve problems independently. It has been suggested that absolute reliance on procedures can stifle critical thinking and can lower learner confidence when faced with non-routine algebraic problems that call for analytical flexibility.

The current discussion about heuristic and algorithmic methods has thus matured and become a pedagogical one, between conceptual understanding and procedural mastery in mathematics education. Previous literature indicates that both have pedagogic strengths, but opinions differ on which method of instruction would yield better performance for algebraic problem solving for secondary school students. Heuristic oriented instructional strategies with visual representations proved to be effective in enhancing learners' mathematical problem solving skills by fostering conceptual involvement and strategic thinking as reported by Kaitera and Harmoinen (2022). On the other hand, defenders of the algorithmic approach argue that steps of precision and logical order are still essential to mathematical skills, and this is especially important in algebraic manipulation, where precise steps are essential. Apart from mathematics teaching, comparative studies between heuristic and algorithmic systems in computational and optimization sciences have shown valuable lessons regarding efficiency, adaptability and quality of solutions. It has been proven that flexible heuristic systems often perform better than rigid procedural algorithms working under complex problem conditions with multiple possibilities and uncertainties (Ay et al., 2023; Abualigah et al., 2023). Likewise, some recent advancements in meta heuristic optimization, such as artificial lemming algorithm, superb fairy wren optimization algorithm, polar fox optimization algorithm, and geyser inspired optimization techniques have focused on adaptability and intelligent exploration as key factors in effective problem-solving (Xiao et al., 2025; Jia et al., 2025; Ghasemi et al., 2024; Ghiaskar et al., 2024). These studies, which were mainly in engineering and computational sciences, have been significant in terms of their theoretical implications for educational problem solving, since they confirm the superiority of flexible reasoning under cognitively challenging conditions. However, the implication of the heuristic principles in computational sciences to the teaching and learning of mathematics in secondary schools has not been fully investigated in the context of the Nigerian educational system.

Empirical studies on heuristic and algorithmic systems have grown significantly in mathematics education, optimization science, engineering, and computational intelligence. But, there is still relatively limited research on direct comparisons of heuristic and algorithmic approaches to teaching in secondary school algebra. Kaitera and Harmoinen (2022) studied the effect of visual heuristic strategies on mathematical problem solving of primary school students and concluded that heuristic teaching method gives a significant effect to the reasoning ability and concept ability of students. They found that learners who received the heuristic exploration had the higher ability in terms of strategic flexibility and problem interpretation than those who received the conventional procedural approach. In the field of computational sciences, Rokbani et

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

al. (2021) found that bi heuristic optimization systems also achieved better efficiency in the solution of complex traveling salesman problems, where adaptive exploration and strategic flexibility in the journey is required. Braik et al., (2020) also reported that capuchin search algorithms improved optimization performance in an intelligent heuristic manner. All these results support the overall conclusion that the heuristic reasoning leads to better problem solving in cognitively demanding situations. Wang et al. (2021) have shown that binary chimp optimization algorithms obtained efficient solutions in the complex optimization environment with uncertainty and dynamic variables. Similarly, Ghiaskar et al. (2024) found that polar fox optimization systems were able to enhance adaptive problem solving using strategic search mechanisms. These studies confirm the theoretical argument that in a dynamic problem situation, systems based on flexible heuristics can be superior to systems based on rigid algorithms. In addition, comparative analyses by Ay et al., (2023) showed that heuristic optimisation techniques yielded better classification results in machine learning applications compared to conventional procedural models. Abualigah et al., (2023) also found heuristic optimization systems to be more adaptive and efficient in image segmentation. Though these studies began in the realm of computational science, their implications can be applied to mathematics education since these studies highlight flexibility and strategic thinking as a key factor in effective problem solving. Although the existing literature on heuristic optimization presents its application in secondary school mathematics education, there are still significant empirical gaps especially in Nigeria. Previous researches have focused on computational optimization instead of classroom instructional practices. Moreover, there is little or no empirical study that has investigated the comparative study of heuristic and algorithmic instructional strategies in algebraic problem solving of secondary school students in Bayelsa State. Studies on mathematics education in Nigeria have been mostly descriptive or experimental comparisons, involving achievement and retention outcomes only and were not conducted with great rigor. This empirical gap is significant as contextual factors such as teacher quality, resources, classroom conditions and learner preparedness may have a significant impact on the effectiveness of instructional approaches. Thus, results from other educational institutions or computation contexts cannot be easily transferred to secondary school mathematics classroom in Bayelsa State. Hence, this study compares and contrast heuristic and algorithmic approaches of instruction with respect to students' achievement and retention of algebraic problem solving through experiments. It is specifically designed to find out if heuristic instructional strategies generated statistically significant results in students' algebraic problem solving performance, as opposed to conventional algorithmic instructional strategies.

Research Questions

The study addressed the following research questions:

1. What difference existed in the achievement scores of students taught algebraic problem solving using heuristic and algorithmic approaches in secondary schools in Bayelsa State?
2. What difference existed in the retention scores of students taught algebraic problem solving using heuristic and algorithmic approaches in secondary schools in Bayelsa State?

Hypotheses

H_{o1}: There is no significant difference in the achievement scores of students taught algebraic problems solving using heuristic and algorithmic approaches in secondary schools in Bayelsa State

H_{o2}: There is no significant difference in the retention scores of students taught algebraic problems solving using heuristic and algorithmic approaches in secondary schools in Bayelsa State

METHODOLOGY

To investigate the comparative effectiveness of heuristic and algorithmic instructional approaches on students' algebraic problem solving achievement and retention in public secondary schools, in Bayelsa State, pretest-posttest retention test quasi experimental research design was used. The design was deemed appropriate because the class groups were intact (no random assignment of students) and the structure of the classroom teams remained intact throughout the school term, while at the same time, the different

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

instructional treatments could be compared. This study used a non-equivalent control group design of two experimental groups using differing instructional methods. The subjects of the study were all the SS2 students in the public secondary schools of the selected local government areas of Bayelsa state offering mathematics as a subject. The choice of Senior Secondary School Two students was due to the fact that algebraic problem solving is a key content of the mathematics curriculum and they have already had adequate mathematical experiences to be used in the experiment. The study was carried out in some public secondary schools in Yenagoa, Ogbia and Sagbama to ensure that a wide range of educational settings both urban and semi urban are represented. A multistage sampling technique was used in selecting the study participants. The first type of sampling employed was purposive sampling in which schools that have similar instructional facilities as well as qualified mathematics teachers and consistent participation in senior secondary school mathematics examination were selected. Simple random sampling was then used to allocate selected schools to heuristic instructional, and algorithmic instructional groups. The final sample to take the experiment comprised of 240 Senior Secondary School Two students from six public secondary schools with 120 in heuristic instructional group while 120 were in algorithmic instructional group. An Algebraic Problem Solving Achievement Test designed by the researcher was used for the collection of data based on senior secondary school mathematics curriculum. The instrument comprised structured algebraic problem solving items on linear equations, simultaneous equations, algebraic expressions, factorization and word problems. Conceptual and procedural competences in algebraic problem solving were both assessed. The content and face validity of the instrument were held by experts in the field of mathematics education and educational measurement. Their observations informed the changes made in terms of clarity, relevance, difficulty level, and the goals of the study.

The instrument was piloted among students not included in the study sample for its reliability, which was determined by Kuder Richardson Formula 20 technique. The instrument had a reliability coefficient of 0.84 which was satisfactory. Both groups were pretested on algebraic problem solving prior to administration of the treatment to ensure that the groups were equivalent across the pretest. The heuristic instructional group was then provided with instructional strategies focusing on exploratory reasoning, guided discovery, pictorial representations, strategic questioning, pattern discovery and multiple solution pathways in algebraic problem solving situations. Throughout classroom interactions students were encouraged to discuss other ways, interpret symbolically relationships conceptually and justify the reasoning processes. In contrast, the algorithmic instructional group was taught using the traditional step-by-step approaches with focus on formula use, repetition of procedure, sequential computation and teacher demonstrations. Both instructional treatments were implemented over a six-week period with trained mathematics teachers, standardized lesson plans prepared by the researcher.

The Algebraic Problem Solving Achievement Test was re-administered as a posttest to both groups at the end of the treatment period to determine achievement differences as a consequence of the instructional approaches. The same instrument as used for the post test was reshuffled and used as a retention test to determine the degree to which algebraic concepts and procedures were learned over time 2 weeks after the posttest administration. The data gathered from the study were analyzed using the mean and standard deviation to answer the research questions, while Analysis of Covariance was used to test for any statistically significant differences between the heuristic and the algorithmic instructional groups at 0.05, significance level. Analysis of Covariance was deemed to be the most appropriate as it accounted for the initial group differences by using the pretest scores as covariates and provided the most statistical precision in comparing the posttest and retention results. Data were tabulated and meaning was attributed to the data by examining the statistical patterns and the statistical significance of the results.

RESULTS

Results were presented based on the two research questions used in the study. Pretest and posttest scores of students' were collated and subjected to analyses using SPSS 26.

Research Question One: What difference existed in the achievement scores of students taught algebraic problem solving using heuristic and algorithmic approaches in secondary schools in Bayelsa State?

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

Table 1: Mean and Standard Deviation of Pretest and Posttest Achievement Scores of Students Taught Algebraic Problem Solving Using Heuristic and Algorithmic Approaches

Group	N	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Mean Gain
Heuristic	120	41.26	8.14	78.43	6.21	37.17
Algorithmic	120	40.88	7.97	68.15	7.04	27.27

As seen in Table 1, the mean score of students who were taught using the heuristic instructional approach on pretest was 41.26 and the standard deviation was 8.14 while on posttest the mean score was 78.43 and standard deviation was 6,21. This resulted in the mean gain score of 37.17. A pretest mean score of 40.88 with standard deviation of 7.97 and posttest mean score of 68.15 with standard deviation of 7.04 were obtained by students exposed to algorithmic instructional approach which gave the mean gain score of 27.27. The results showed that there is an increase in students' achievement in algebraic problem-solving skills following the treatment of both the instructional models. But, the achievement gained by the heuristic instructional approach is significantly higher than the algorithmic instructional approach.

Research Question Two: What difference existed in the retention scores of students taught algebraic problem solving using heuristic and algorithmic approaches in secondary schools in Bayelsa State?

Table 2: Mean and Standard Deviation of Retention Scores of Students Taught Algebraic Problem Solving Using Heuristic and Algorithmic Approaches

Group	N	Posttest Mean	Posttest SD	Retention Mean	Retention SD	Retention Loss
Heuristic	120	78.43	8.14	74.62	5.98	3.81
Algorithmic	120	68.15	7.97	59.31	6.87	8.84

The results contained in Table 2 shows that the students who learned algebraic problem solving with heuristic teaching model resulted in the value of mean score of 74.62 and standard deviation score of 5.98. The group had a retention loss of only 3.81 points from the post test score. Students in the algorithmic instructional approach, on the other hand, had a retention mean score of 59.31, standard deviation of 6.87, and retention loss of 8.84 points from the posttest score. The results showed that the students who were taught with heuristic instructional strategies had learned significantly more algebraic knowledge than the students taught using algorithmic instructional methods. The lower level of retention loss was found in the heuristic group, indicating that heuristic teaching helped students to process deeper cognition, thus improving their long-term understanding of the concept of algebra. Analysis of Covariance was used to determine if the difference in retention observed was statistically significant, controlling for the differences in posttests.

Hypotheses Testing

Ho_1: There is no significant difference in the achievement scores of students taught algebraic problems solving using heuristic and algorithmic approaches in secondary schools in Bayelsa state

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

Table 3: Analysis of Covariance of Posttest Achievement Scores of Students Taught Algebraic Problem Solving Using Heuristic and Algorithmic Approaches

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	14872.514	2	7436.257	98.462	.000
Intercept	31264.118	1	31264.118	413.967	.000
Pretest	2284.436	1	2284.436	30.273	.000
Instructional Approach	6941.282	1	6941.282	91.884	.000
Error	17892.407	237	75.495		
Total	1320160.000	240			
Corrected Total	32764.921	239			

The result of the Analysis of Covariance in Table 3 showed that students' achievement in algebraic problem solving was statistically significant for instructional approach with $F(1,237) = 91.884$ and $\alpha < .05$. The difference between the heuristic and algorithmic instructional groups was statistically significant as the probability value (p) of .000 was less than the predetermined significance level of .05. Thus, the results showed that the students taught algebraic problem solving by using heuristic instructional approach had significant differences in the results of their learning with the students taught by algorithmic instructional approach. The large effect found despite controlling for pretest scores indicates that the difference in achievement could be explained for most part by the instructional treatment; preexisting group differences did not account for the difference.

H_{o2}: There is no significant difference in the retention scores of students taught algebraic problems solving using heuristic and algorithmic approaches in secondary schools in Bayelsa State

Table 4: Analysis of Covariance of Retention Scores of Students Taught Algebraic Problem Solving Using Heuristic and Algorithmic Approaches

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	11984.366	2	5992.183	87.321	.000
Intercept	28611.702	1	28611.702	416.991	.000
Posttest Score	1942.157	1	1942.157	28.305	.000
Instructional Approach	5827.643	1	5827.643	84.923	.000
Error	16266.941	237	68.636		
Total	1185410.000	240			
Corrected Total	28251.307	239			

The Analysis of Covariance results in Table 4 revealed that instructional approach exerted a statistically significant effect on students' retention in algebraic problem solving, $F(1,237) = 84.923$, $p < .05$. Since the significance value of .000 was lower than the .05 threshold. Hence, the hypothesis of there is no significant difference in the retention scores of students taught algebraic problems solving using heuristic and

algorithmic approaches was rejected. This implies that the difference between the heuristic and algorithmic instructional groups in retention performance was statistically significant.

Discussion of Findings

The findings revealed that students who were taught with heuristic instructional strategies showed a significant retentive knowledge of algebraic problem solving over students who were taught with algorithmic instructional strategies. The better retention results found in the heuristic group indicated that heuristic learning experiences led to increased conceptual encoding and enhanced cognitive integration of mathematical knowledge. The results support the information processing theory that focuses on meaningful learning, which is learning that takes place when learners process, organize and interpret information in a cognitive way. The result is also in tandem with that of Kaitera and Harmoinen (2022) which revealed that Heuristic Oriented Instructional Strategies had a significant impact on mathematical reasoning and problem solving performance in conceptual engagement and strategic thinking. The results further aligns with overall evidence of heuristic optimization studies, that found flexible reasoning systems to outperforming in cognitively demanding situations (Rokbani et al., 2021; Braik et al., 2020). The heuristic instructional approach seemed to have the effect of increasing students' conceptual understanding and analytical flexibility by providing opportunities for students to explore various ways of solving the problem without relying on the rote memorization of procedures. The findings also confirm the assumptions of the constructivist learning theory which posits that learners will gain deeper knowledge if they participate in the process of building up knowledge. During class, students in the heuristic group were asked to interpret algebraic relationships on their own, explain their interpretation and check other ways of doing it. These learning experiences seemed to have a significant influence on enhancing the conceptual understanding and confidence in problem solving. On the other hand, the mean score of the posttest for the algorithmic instructional approach showed that the procedural instruction alone might not be enough to enhance students' adaptive reasoning skills needed to be able to solve algebraic problems. Students who were taught algebraically often relied on memorized procedures, and lacked flexibility when faced with new algebraic problems. This observation aligns with Yildiz et al.'s (2020) and Selvarajan's (2024) concern that rigid procedural systems tend to have lower adaptability when dealing with complex problem scenarios.

CONCLUSION

Both algorithmic and heuristic methods led to an increase in students' achievement in algebraic problem solving following the treatment period. The heuristic group demonstrated better conceptual understanding and more analytical flexibility with ability to interpret algebraic relationships in problem solving activities that translated into better retention result. The superiority of heuristic instruction over algorithmic approach was gravitated by the continuous emphasis on exploratory reasoning, conceptual engagement, strategic inquiry as well as active learner engagement in the mathematical problem solving process.

Recommendations

Based on the findings, the following recommendations were made.

- Mathematics teachers should employ heuristic methods in classroom discussions to enhance students' ability to analyze, explore, visualize and justify the relations that exists between concepts in mathematics.

- Mathematics curriculum planners and educational authorities should reconsider the frameworks of mathematics teaching and learning to include more attention to strategic problem solving, conceptual understanding, and learner centered inquiry in the teaching of algebra.

- Teacher education programs should focus on professional development of the heuristic approaches of teaching and learning to prepare the mathematics teachers with pedagogical skills to create a classroom environment that is exploratory and conceptually oriented.

REFERENCES

1. Abualigah, L., Almotairi, K. H., & Elaziz, M. A. (2023). Multilevel thresholding image segmentation using meta-heuristic optimization algorithms: Comparative analysis, open challenges and new trends. *Applied Intelligence*, *53*(10), 11654-11704. https://doi.org/10.1007/s10489-022-04064-4
2. Alsattar, H. A., Zaidan, A. A., & Zaidan, B. B. (2020). Novel meta-heuristic bald eagle search optimisation algorithm. *Artificial Intelligence Review*, *53*(3), 2237-2264. https://doi.org/10.1007/s10462-019-09732-5
3. Braik, M., Sheta, A., & Al-Hiary, H. (2020). A novel meta-heuristic search algorithm for solving optimization problems: capuchin search algorithm. *Neural computing and applications*, *33*(7), 2515-2547. https://doi.org/10.1007/s00521-020-05145-6
4. Dereli, S., & Köker, R. (2020). A meta-heuristic proposal for inverse kinematics solution of 7-DOF serial robotic manipulator: quantum behaved particle swarm algorithm. *Artificial Intelligence Review*, *53*(2), 949-964.
5. Ekinci,Ay, Ş., E., & Garip, Z. (2023). A comparative analysis of meta-heuristic optimization algorithms for feature selection on ML-based classification of heart-related diseases: Ş. Ay et al. *The Journal of Supercomputing*, *79*(11), 11797-11826. https://doi.org/10.1007/s11227-023-05132-3
6. Ghasemi, M., Zare, M., Zahedi, A., Akbari, M. A., Mirjalili, S., & Abualigah, L. (2024). Geyser inspired algorithm: a new geological-inspired meta-heuristic for real-parameter and constrained engineering optimization. *Journal of Bionic Engineering*, *21*(1), 374-408. https://doi.org/10.1007/s42235-023-00437-8
7. Ghiaskar, A., Amiri, A., & Mirjalili, S. (2024). Polar fox optimization algorithm: a novel meta-heuristic algorithm. *Neural Computing and Applications*, *36*(33), 20983-21022. https://doi.org/10.1007/s00521-024-10346-4
8. Jia, H., Zhou, X., Zhang, J., & Mirjalili, S. (2025). Superb Fairy-wren Optimization Algorithm: a novel metaheuristic algorithm for solving feature selection problems. *ClusterComputing*, *28*(4). https://doi.org/10.1007/s10586-024-04901-w
9. Joseph, S. B., Dada, E. G., Abidemi, A., Oyewola, D. O., & Khammas, B. M. (2022). Metaheuristic algorithms for PID controller parameters tuning: Review, approaches and open problems. *Heliyon*, *8*(5), e09399. doi.org/10.1016/j.heliyon...
10. Kahraman, H. T., Bakir, H., Duman, S., Katı, M., Aras, S., & Guvenc, U. (2022). Dynamic FDB selection method and its application: modeling and optimizing of directional overcurrent relays coordination: HT Kahraman et al. *Applied Intelligence*, *52*(5), 4873-4908. https://doi.org/10.1007/s10489-021-02629-3
11. Kaitera, S., & Harmoinen, S. (2022). Developing Mathematical Problem-Solving Skills in Primary School by Using Visual Representations on Heuristics. *LUMAT: International Journal on Math, Science and Technology Education, 10(*2), 111-146. https://doi.org/10.31129/lumat.10.2.1696
12. Nabi, S., Ahmad, M., Ibrahim, M., & Hamam, H. (2022). AdPSO: adaptive PSO-based task scheduling approach for cloud computing. *Sensors*, *22*(3), 920.
13. Rokbani, N., Kumar, R., Abraham, A., Alimi, A. M., Long, H. V., Priyadarshini, I., & Son, L. H. (2021). Bi-heuristic ant colony optimization-based approaches for traveling salesman problem. *Soft Computing*, *25*(5), 3775-3794.
14. Selvarajan, S. (2024). A comprehensive study on modern optimization techniques for engineering applications. *Artificial Intelligence Review*, *57*(8), 194.
15. Singh, E., & Pillay, N. (2022). A study of ant-based pheromone spaces for generation constructive hyper-heuristics. *Swarm and Evolutionary Computation*, *72*, 101095.
16. Tripathi, D. R., Vachhani, K. H., Bandhu, D., Kumari, S., Kumar, V. R., & Abhishek, K. (2021). Experimental investigation and optimization of abrasive waterjet machining parameters for GFRP composites using metaphor-less algorithms. *Materials and Manufacturing Processes*, *36*(7), 803-813.
17. Wang, J., Khishe, M., Kaveh, M., & Mohammadi, H. (2021). Binary chimp optimization algorithm (BChOA): a new binary meta-heuristic for solving optimization problems. *Cognitive Computation*, *13*(5), 1297-1316.

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume XI Issue VII July 2026

18. Xiao, Y., Cui, H., Khurma, R. A., & Castillo, P. A. (2025). Artificial lemming algorithm: a novel bionic meta-heuristic technique for solving real-world engineering optimization problems. *Artificial Intelligence Review*, *58:84*
19. Yildiz, A. R., Abderazek, H., & Mirjalili, S. (2020). A Comparative Study of Recent Non-traditional Methods for Mechanical Design Optimization: AR Yildiz et al. *Archives of Computational Methods in Engineering*, *27*(4), 1031-1048.