Journal of Studies in Science and Mathematics Education
ISSN: 2630-662x
Published: 17.08.2026
Volume (issue): *6*(1)
Page: 252–258

Effect of Polya's Problem-Solving Strategy on Academic Performance and Self-Efficacy in Thermochemistry among Secondary School Students, Funtua Zone, Katsina State, Nigeria

Samuel Kelvin and Abdullahi Lawal*

Department of Science Education, Ahmadu Bello University, Zaria, Nigeria

***Corresponding author:** *alawal@education.abu.edu.ng*

Abstract

This study investigated the effect of Polya's problem-solving strategy on academic performance and self-efficacy in thermochemistry among senior secondary school chemistry students in Funtua Education Zone, Katsina State, Nigeria. A quasi-experimental pre-test, post-test non-equivalent control group design was adopted. The population comprised 4,250 Senior Secondary II (SSII) chemistry students across the zone. A sample of 180 students was drawn using multi-stage and purposive sampling techniques from two co-educational schools, assigned to experimental (Polya's strategy, $n = 92$) and control (conventional teaching method, $n = 88$) groups. Two validated instruments, the Thermochemistry Performance Test (TPT, $r = 0.84$) and the Thermochemistry Self-Efficacy Questionnaire (TSEQ, $\alpha = 0.88$), were used for data collection. Data were analyzed using mean, standard deviation, and Analysis of Covariance (ANCOVA) at the 0.05 level of significance. Findings revealed that students taught using Polya's strategy achieved significantly higher post-test academic performance scores than those taught conventionally, $F(1, 177) = 42.15$, $p < .001$, partial $\eta^2 = .19$ (Cohen's $d = 2.23$). Polya's strategy also significantly enhanced students' thermochemistry self-efficacy beliefs, $F(1, 177) = 31.44$, $p < .001$, partial $\eta^2 = .15$ (Cohen's $d = 2.84$). Both effect sizes are large by conventional standards, indicating that the advantage of Polya's strategy is educationally, and not merely statistically, meaningful. The study concludes that Polya's heuristic sequence is an effective pedagogical framework for reducing abstract bottlenecks in chemistry instruction and recommends its integration into mainstream science teacher-preparation curricula.

Keywords: Polya's strategy, problem-solving, academic performance, self-efficacy, thermochemistry

1 Introduction

The introduction should be succinct and contain no subheadings. This section should present background for the study, Chemistry is a foundational pillar of science education that plays a fundamental role in driving industrialization, technological advancement, and economic sustainability. Within the secondary school chemistry curriculum, physical chemistry concepts form a significant core, with thermochemistry representing a critical and heavily weighted node. Thermochemistry explores quantitative heat transformations during physical and chemical changes, requiring students to concurrently synthesize abstract conceptual definitions with mathematical algorithms, system-boundary interpretations, and thermodynamic laws. Despite its instructional importance, contemporary empirical studies highlight a persistent trend of poor academic performance among secondary school students in chemistry, specifically within abstract and mathematical areas like thermochemistry, chemical bonding, and stoichiometry (Okanlawon, 2020).

Traditional chemistry instruction has predominantly relied on teacher-centered, expository ("chalk-and-talk") methods that emphasize passive note-taking and rote computational routines, in which students memorize formulas without deep conceptual internalization. When confronted with novel thermodynamic problem configurations, students often experience cognitive overload, resulting in procedural errors and diminished confidence. This persistent pattern constitutes the central problem addressed by this study: conventional instructional approaches appear insufficient for building both the procedural competence and the self-belief that thermochemistry demands, creating a need for structured, student-centered problem-solving strategies that promote active inquiry and logical reasoning (Ganajóvá et al., 2025; Aliyu et al., 2024).

The purpose of this study was to determine the effect of Polya's problem-solving strategy on academic performance and self-efficacy in thermochemistry among SSII students in Funtua Education Zone, Katsina State. Evidence from this study is of practical significance to curriculum planners and textbook developers seeking heuristic-based instructional models for physical chemistry, to teacher-training institutions designing pedagogy courses for pre-service chemistry teachers, and to classroom chemistry teachers preparing candidates for the West African Senior School Certificate Examination

(WASSCE), where poor performance in calculation-based topics remains a recurring concern. Specifically, the findings inform decisions about whether structured heuristic strategies should be prioritized over expository methods when teaching abstract, calculation-intensive chemistry topics.

1.1 Research Questions

This study was guided by the following research questions:

1. What is the effect of Polya's problem-solving strategy on students' post-test academic performance scores in thermochemistry compared with the conventional teaching method?
2. What is the effect of Polya's problem-solving strategy on students' post-test self-efficacy scores in thermochemistry compared with the conventional teaching method?

1.2 Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

H_{01}: There is no significant difference in the post-test mean academic performance scores in thermochemistry between students taught using Polya's problem-solving strategy and those taught using the conventional teaching method.

H_{02}: There is no significant difference in the post-test mean self-efficacy scores in thermochemistry between students taught using Polya's problem-solving strategy and those taught using the conventional teaching method.

2 Theoretical Framework

This study is anchored on two complementary theoretical perspectives: Polya's (1957) problem-solving framework and Bandura's (1997) Social Cognitive Theory of self-efficacy. Polya's (1957) framework conceptualizes quantitative problem-solving as a sequence of four recursive stages: understanding the problem, devising a plan, carrying out the plan, and looking back. Applied to thermochemistry, the framework predicts that students explicitly guided to identify known and unknown quantities, select an appropriate thermodynamic relationship, execute the calculation systematically, and verify the reasonableness of their answer will make fewer procedural errors than students who apply memorized formulas without this structure. This proposition generated Hypothesis 1: that the structured heuristic sequence would produce measurably higher academic performance than conventional instruction.

Bandura's (1997) Social Cognitive Theory holds that self-efficacy, the belief in one's capability to organize and execute the courses of action required to produce given attainments, develops primarily through four sources: mastery experiences, vicarious experiences, verbal persuasion, and physiological states, of which mastery experience is theorized to be the most influential. Because Polya's framework decomposes complex thermochemical problems into achievable sub-goals, it is theorized to generate repeated, incremental mastery experiences that conventional instruction does not systematically provide. This proposition generated Hypothesis 2: that Polya's strategy would produce measurably higher self-efficacy gains than conventional instruction. Together, these two frameworks position Polya's strategy as the instructional mechanism and Bandura's theory as the psychological mechanism through which the hypothesized performance and self-efficacy gains were expected to occur, and they informed both the design of the intervention and the selection of the TPT and TSEQ as outcome measures.

2.1 Literature Review

A recurring challenge in science and mathematics education, particularly in calculation-heavy domains such as stoichiometry, redox reactions, and thermochemistry, is students' tendency to apply algorithmic procedures without conceptual understanding. Structured, student-centered interventions have increasingly been proposed as a corrective. Empirical evidence on Polya's four-stage heuristic is broadly consistent in direction, though it spans different content domains. In geometry, Obinatu and Omebe (2025) found that SSII students taught using Polya's strategy achieved significantly higher mean achievement scores than students taught with the conventional chalk-and-talk method, $F(1, 212) = 577.29$, $p < .001$. In a related problem-solving model, Babangida and Bashir (2025) reported that structured, stepwise instruction significantly improved secondary students' performance in a respiration-related biology topic, suggesting that the benefit of decomposing abstract content into systematic components is not confined to a single subject. When applied specifically to chemical calculations, Okanlawon (2020) found that guided, stepwise problem-solving fosters directed discovery, intensifies student focus, and improves post-test chemistry achievement, a pattern the present study extends to thermochemistry specifically.

Beyond cognitive outcomes, science education research increasingly examines self-efficacy as a co-outcome of instructional design. Bada and Jita (2023) found that instructional strategies which actively scaffold complex physical-science topics, such as heat and energy, simultaneously improve students' conceptual retention and their self-efficacy ratings, indicating that cognitive and affective gains from structured instruction tend to co-occur rather than trade off. Ganajóvá et al., (2025) similarly found that inquiry-based teaching improved students' attitudes toward science subjects across physics, chemistry, and biology, reinforcing that active, structured pedagogies carry affective as well as cognitive benefits. Consistent with this, Aliyu, Abdullahi, and Garba (2024), in a systematic review of PhET-simulation-based chemistry instruction, found that active, technology-supported instructional strategies were most effective when paired with guided, structured approaches such as inquiry and problem-based learning, rather than open-ended exploration. Taken together, this body of work supports two inferences that motivate the present study: first, that structured heuristic strategies such as Polya's tend to outperform conventional instruction on cognitive outcomes across mathematics and science domains; second, that self-efficacy gains typically accompany, rather than substitute for, these cognitive gains when a strategy provides systematic mastery opportunities. However, none of the reviewed studies examined Polya's strategy specifically within thermochemistry, the abstract, calculation-intensive topic that motivates the present study's focus.

3 Methodology

3.1 Research Design

A quasi-experimental pre-test, post-test non-equivalent control group design was adopted.

3.2 Sample/Participants

The study was conducted within the Funtua Education Zone of Katsina State, Nigeria, a region characterized by a mixture of rural and semi-urban public schools. The target population comprised 4,250 Senior Secondary Class II (SSII) chemistry students during the 2025/2026 academic session. Two co-educational public secondary schools were selected through purposive sampling, based on comparability in infrastructural facilities, availability of experienced chemistry staff, and a history of presenting candidates for the West African Senior School Certificate Examination (WASSCE). School A was designated as the Experimental Group ($n = 92$) and was taught using Polya's problem-solving strategy. School B served as the Control Group ($n = 88$) and was instructed using the Conventional Teaching Method (CTM). The treatment span covered six consecutive weeks. All 180 students who commenced the study completed the full six-week intervention; no attrition or absenteeism affecting data collection was recorded.

3.3 Instrumentation

Data collection relied on two instruments developed by the authors: the Thermochemistry Performance Test (TPT) and the Thermochemistry Self-Efficacy Questionnaire (TSEQ). The TPT consisted of 25 multiple-choice questions and 5 structured numerical problems addressing heat of neutralization, enthalpy of combustion, Hess's Law, and bond energy calculations. The TPT was validated by three subject-matter specialists in the Department of Science Education, Ahmadu Bello University, Zaria. Reliability indices were established via a pilot test on 30 non-participating students, yielding a split-half reliability coefficient of $r = 0.84$. The TSEQ comprised 20 items structured on a 4-point Likert scale, ranging from Strongly Agree (4) to Strongly Disagree (1), assessing confidence dimensions. The TSEQ achieved an internal consistency Cronbach's alpha of $\alpha = 0.88$. Both instruments were administered by the researchers, with the regular chemistry teacher of each school acting as an invigilator. The pre-tests were administered one week before the intervention began, and the post-tests were administered immediately after the six-week treatment period, under standardized, supervised examination conditions in both schools.

3.4 Data Analysis

Mean and standard deviation were used to answer descriptive questions, while Analysis of Covariance (ANCOVA) was used to test both null hypotheses at the 0.05 level of significance, with pre-test scores entered as the covariate. Prior to conducting ANCOVA, the assumptions of homogeneity of regression slopes (no significant interaction between the covariate and treatment group), normality of residuals, and homogeneity of variance (Levene's test) were examined for both outcome variables. Effect sizes are reported as partial eta squared (partial η^2) for the ANCOVA models and as Cohen's d for the standardized mean difference between post-test group means, interpreted using Cohen's (1988) conventions (small = .01/0.2, medium = .06/0.5, large = .14/0.8 for partial η^2 and d, respectively).

4 Results

Hypothesis 1 stated that there is no significant difference in the post-test mean academic performance scores in thermochemistry between students taught using Polya's problem-solving strategy and those taught using the conventional instruction method. Table 1 presents the baseline and post-test descriptive indicators for academic performance across groups.

Table **1**

Descriptive Statistics for Pre-test and Post-test Performance Scores

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD
Experimental (Polya)	92	34.15	6.20	68.42	7.15
Control (Conventional)	88	33.84	5.94	51.10	8.34

The pre-test means for the two groups were closely matched (Experimental M = 34.15; Control M = 33.84), supporting the initial equivalence of the groups prior to treatment. Both groups improved substantially by post-test; notably, the Control group's gain of approximately 17 points is itself considerable, which is consistent with ordinary classroom instruction, continued exposure to thermochemistry content across the six-week period, and a test-retest practice effect from encountering a structurally similar post-test, rather than an absence of learning in the conventional condition. The critical comparison for this study is therefore not whether the Control group improved, but whether the Experimental group's improvement exceeded it after adjusting for pre-test differences. To analyze the significance of the post-test score adjustments while isolating the variance added by pre-treatment baselines, a one-way Analysis of Covariance (ANCOVA) was conducted. The results are presented in Table 2.

Table **2**

ANCOVA Summary of Students' Post-test Performance in Thermochemistry

Source	Type III SS	df	Mean Square	F	p	partial η^2
Corrected Model	13421.40[a]	2	6710.70	110.22	<.001	—
Intercept	24150.11	1	24150.11	396.65	<.001	—
Pre-test Score	412.50	1	412.50	6.78	.010	.037
Group (Treatment)	2566.25	1	2566.25	42.15	<.001	.192
Error	10776.54	177	60.88	—	—	—

Table 2 indicates a highly significant effect of the pedagogical treatment group on post-test performance, $F(1, 177) = 42.15$, $p < .001$, partial $\eta^2 = .19$, indicating that group membership accounted for approximately 19% of the variance in post-test performance after adjusting for pre-test scores. The standardized mean difference between groups was similarly large, Cohen's d = 2.23, indicating that the average student in the Experimental group scored more than two pooled standard deviations above the average Control-group student. The null hypothesis was therefore rejected, demonstrating that Polya's structured heuristic sequence elevated quantitative understanding of thermochemistry substantially beyond what conventional instruction achieved, including beyond the gain observed in the Control group itself. Hypothesis 2 stated that there is no significant difference in the post-test mean self-efficacy scores in thermochemistry between students exposed to Polya's problem-solving strategy and those exposed to the conventional teaching method. Table 3 presents the descriptive statistics for students' self-efficacy scores.

Table **3**

Descriptive Statistics for Pre-test and Post-test Self-Efficacy Scores

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD
Experimental (Polya)	92	42.30	5.12	74.85	6.40
Control (Conventional)	88	41.95	5.33	54.60	7.82

To isolate the significance of the post-test self-efficacy score adjustments while accounting for initial baseline variance, a second ANCOVA was conducted. Table 4 summarizes this analysis.

Table **4**

ANCOVA Summary of Students' Post-test Self-Efficacy in Thermochemistry

Source	Type III SS	df	Mean Square	F	p	partial η^2
Corrected Model	16204.12[b]	2	8102.06	131.65	<.001	—
Intercept	31245.80	1	31245.80	507.72	<.001	—
Pre-test Self-Eff.	390.40	1	390.40	6.34	.013	.035
Group (Treatment)	1934.85	1	1934.85	31.44	<.001	.151
Error	10892.68	177	61.54	—	—	—

As shown in Table 4, the treatment factor (Group) exerted a highly significant influence on post-treatment self-efficacy scores, $F(1, 177) = 31.44$, $p < .001$, partial $\eta^2 = .15$, a large effect indicating that treatment group accounted for approximately 15% of the variance in post-test self-efficacy after adjusting for pre-test scores. The standardized mean difference was likewise large, Cohen's $d = 2.84$. The second null hypothesis was therefore rejected, confirming that Polya's stepwise framework acted as a substantial enhancer of students' chemistry self-efficacy.

5 Discussion

The results of this study indicate that Polya's problem-solving strategy significantly enhanced both academic performance and self-efficacy in thermochemistry, with effect sizes in both cases classified as large by Cohen's (1988) conventions. As anchored in the Theoretical Framework above, this pattern is consistent with Polya's (1957) proposition that decomposing quantitative tasks into sequential, verifiable stages reduces the cognitive load associated with concurrently managing structural chemical changes and numeric parameters. Under conventional instruction, students frequently combine formulas without first establishing conceptual representations of the problem, which is consistent with prior findings that unstructured routines lead novice problem-solvers into persistent errors (Okanlawon, 2020). Although the Control group's own post-test gain was considerable, ordinary classroom exposure over six weeks plainly produced some learning, the additional gain attributable to Polya's strategy, evidenced by the large partial eta-squared and Cohen's d values reported above, indicates that the strategy's benefit is not merely statistically significant but educationally meaningful. A seventeen-point average advantage on a scale where the Control group itself improved substantially represents a difference unlikely to be explained by maturation or practice effects alone.

Regarding self-efficacy, the results align with Bandura's (1997) proposition that mastery experiences are the most influential source of self-efficacy beliefs. In conventional classrooms, chemistry numerical problems are often treated as disjointed formulas to memorize; when students fail to replicate calculations under slightly altered contextual variables, they experience repeated failures that can depress their confidence. Polya's method restructures this dynamic by breaking tasks into digestible heuristic steps, allowing students to establish incremental targets and accumulate authentic mastery experiences, consistent with the theoretical mechanism proposed above and with prior findings that structured, scaffolded instruction improves both retention and self-efficacy together (Bada & Jita, 2023). By explicitly practicing Polya's first step, understanding the problem, students in the Experimental group were systematically trained to isolate known quantities, write balanced thermochemical equations, and check units before beginning calculations. This likely reduced procedural failure rates and, consistent with Bandura's mastery-expectation hypothesis, is a plausible mechanism through which resolving sequential sub-problems without repeated failure produced a reinforcing cycle of confidence and sustained academic effort.

6 Limitations

Several limitations should be considered when interpreting these findings. First, the quasi-experimental, non-equivalent control group design, necessitated by the ethical and practical impossibility of randomly assigning individual students to instructional methods within intact schools, limits the strength of causal claims that can be drawn; unmeasured school-level differences may have contributed to the observed effects despite the comparability criteria used in school selection. Second, the study was conducted in only two schools within a single education zone, which limits the generalizability of the findings to other zones, states, or school types within Nigeria. Third, the six-week treatment duration, while sufficient to detect immediate post-test effects, does not permit conclusions about the long-term retention of either performance gains or self-efficacy beliefs. Finally, both the TPT and TSEQ were researcher-developed instruments; although validated and pilot-tested, their psychometric properties have not yet been cross-validated in independent samples.

7 Future Research

Future studies should consider a longitudinal design that re-tests participants several months after the intervention to establish whether performance and self-efficacy gains from Polya's strategy are retained over time. A multi-site, cluster-based trial spanning several education zones would strengthen causal inference and generalizability beyond the Funtua zone. Further research might also dismantle Polya's four-stage sequence to identify which specific stage, understanding the problem, planning, execution, or verification, contributes most to the observed gains in thermochemistry, which would have direct implications for how teacher-training programs prioritize instructional time.

8 Conclusion

Based on these empirical findings, this study concludes that Polya's problem-solving strategy is a pedagogically effective framework for teaching thermochemistry to secondary school students in the Funtua Education Zone of Katsina State, Nigeria. The strategy significantly improved academic performance and self-efficacy beliefs relative to conventional instruction, with large effect sizes indicating that the advantage is educationally, and not merely statistically, meaningful. It is therefore recommended that secondary science educators transition from purely expository lecture designs toward explicit, step-by-step heuristic models to reduce abstract bottlenecks in physical chemistry instruction, and that teacher-training institutions incorporate Polya's framework into pre-service chemistry pedagogy courses.

9 Declarations

Ethical Statements: Administrative approval and ethical clearance were granted by the Ministry of Education, Katsina State, via the Funtua Zonal Office. Informed assent was obtained from the principals of the participating institutions. Parental consent and individual student verbal assent were secured prior to intervention start. Participant datasets were strictly anonymized, and all educational protocols complied with institutional research guidelines.

Conflict of Interest: The authors declare neither financial nor non-financial conflicts of interest.

Author Contributions: The authors designed the experimental protocol, coordinated field implementation, administered the instruments, and compiled the baseline database, supervised the research structure, refined the statistical analysis framework, and critically revised the manuscript drafts. Both authors approved the final version of the manuscript.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgments: The authors sincerely appreciate the faculty members of the Department of Science Education, Ahmadu Bello University, Zaria, for their structural feedback during validation phases. We also extend our gratitude to the secondary school chemistry teachers and students within the Funtua Zone for their cooperation.

Data Availability Statement: The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable academic request.

10 References

Aliyu, H., Abdullahi, A., & Garba, A. (2024). Role of PhET interactive simulation as virtual technology that facilitates learning of chemistry: A systematic review of chemical concepts, learning theories, instructional modes and strategies. Rima International Journal of Education (RIJE), 3(2).

Babangida, A. K., & Bashir, S. (2025). Effect of Polya's problem-solving model on performance in respiration concept among secondary school students in Zamfara State, Nigeria. Journal of Research in Science and Mathematics Education, 11(2), 275–284.

Bada, A., & Jita, L. (2023). Effect of brain-based teaching strategy on students' retention and self-efficacy in heat energy. Journal of Technology and Science Education, 13(1), 276–287. https://doi.org/10.3926/jotse.1629

Bandura, A. (1997). Self-efficacy: The exercise of control. W. H. Freeman.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences (2nd ed.). Lawrence Erlbaum Associates.

Ganajóvá, M., Orosová, R., Sotáková, I., & Letošníková, P. (2025). The effect of inquiry-based teaching on students' attitudes toward science as an academic subject as well as science and technology in general. Frontiers in Education, 10, Article 1708139. https://doi.org/10.3389/feduc.2025.1708139

Obinatu, B., & Omebe, C. A. (2025). Effect of Polya's problem-solving instructional strategy on senior secondary school students' achievement in geometry. Unizik Journal of Educational Research, Science and Vocational Studies, 2(1), 537–548.

Okanlawon, A. E. (2020). Constructing a pedagogical content knowledge framework for teaching reaction stoichiometry. Chemistry Education Research and Practice, 21(2), 512–525.

Polya, G. (1957). How to solve it: A new aspect of mathematical method (2nd ed.). Princeton University Press.

Publisher's Note