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| RESEARCH ARTICLE

Effect of Problem-Based Learning on the Academic Performance and Perceptions of TVET Students in Nomenclature of Inorganic Compounds

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| ABSTRACT
Students in Technical and Vocational Education and Training (TVET) institutions in Ghana often struggle to master and apply IUPAC nomenclature for inorganic compounds, partly due to limitations of traditional lecture-based instruction. This study examined the effect of Problem-Based Learning (PBL) on students' performance and perceptions in naming inorganic compounds, including potential gender differences. A double-group pretest–posttest quasi-experimental design was used with 85 second-year TVET students from two institutions in Kpando Municipality (experimental = 45; control = 40). The experimental group received an eight-week PBL intervention, while the control group received conventional lectures. Data were collected using the Inorganic Compound Nomenclature Proficiency Test (ICNPT, KR-20 = 0.87) and a Student Perception Questionnaire (SPQ, Cronbach's α = 0.91). Descriptive statistics, independent-samples t-tests, Welch's t-test, and Cohen's d for effect size were used for analysis. Results indicated that students in the PBL group significantly outperformed the control group ($t(83) = 12.29$, $p < 0.05$, $d = 2.71$). No significant gender differences were observed in the experimental group (Welch's $t = 1.316$, $p > 0.05$). Students also reported positive perceptions of PBL, citing increased engagement, confidence, collaboration, and problem-solving skills. The study concludes that PBL enhances academic performance, conceptual understanding, and equitable learning outcomes, while positively influencing students' perceptions. These findings support integrating PBL into TVET chemistry curricula and providing teacher professional development to promote learner-centered, problem-oriented instruction.

| KEYWORDS

Problem-Based Learning, TVET, Inorganic Compounds, Academic Performance, Student Perceptions, Gender Equity

| ARTICLE INFORMATION

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1. Introduction

Technical and Vocational Education and Training (TVET) plays a critical role in preparing students for industry-relevant careers in Ghana. Chemistry, as a core subject, equips students with essential problem-solving, analytical, and critical thinking skills. However, many TVET students struggle with naming inorganic compounds, often confusing oxidation numbers, polyatomic ions, and transition metal compounds. Traditional lecture-based approaches focus on memorization rather than active engagement, limiting conceptual mastery (Boniface et al., 2020).

Problem-Based Learning (PBL) is a student-centered instructional strategy emphasizing active learning, collaboration, and real-world problem solving. It aligns with constructivist principles, fostering knowledge construction through guided inquiry, discussion, and reflection (Hmelo-Silver, 2004). Despite its proven effectiveness in higher education, limited research exists on PBL in Ghanaian TVET, particularly for inorganic compound nomenclature. This study investigates PBL's effect on performance, and student perception in this context.

Research Questions

1. What differences exist between the performance of students exposed to problem-based learning and traditional science instruction in inorganic compound nomenclature?
2. What perceptions do the experimental students hold on the effectiveness of problem-based instruction for lessons on the naming of inorganic compounds?

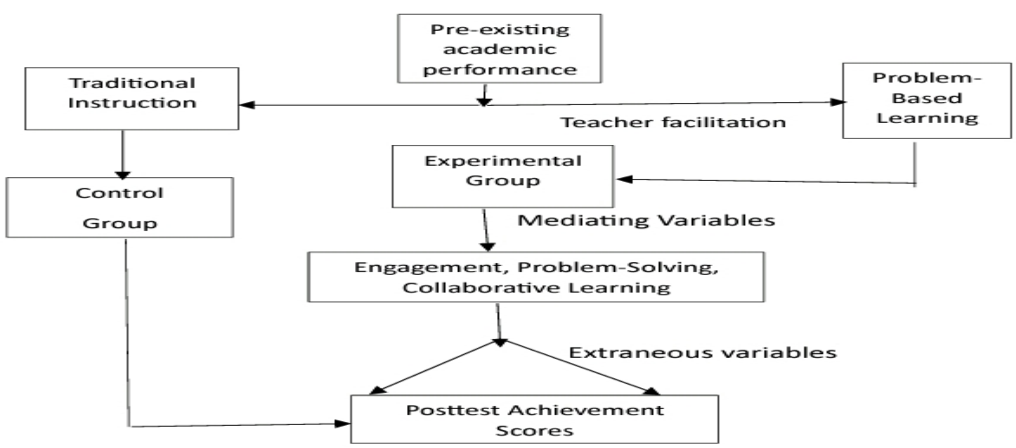
2. Literature Review

PBL promotes critical thinking, collaborative skills, and conceptual understanding. Learners engage with ill-structured real-world problems, analyzing, hypothesizing, researching, and proposing solutions (Savery, 2006). Studies show PBL enhances retention, motivation, and academic achievement across STEM disciplines (Barrows, 2002; Hmelo-Silver, 2004).

Inorganic Compound Nomenclature in TVET IUPAC nomenclature ensures standardization in chemistry communication. Students frequently encounter difficulties with: - Oxidation number assignments - Classification of compounds - Naming polyatomic and transition metal compounds. These challenges impact performance and critical thinking development.

While PBL is widely applied in SHS and tertiary chemistry education, its impact on TVET students in Ghana remains underexplored. This study addresses this gap, evaluating PBL's effect on academic performance, gender equity, and student perceptions.

2.1 Conceptual Framework



3. Methodology

The study employed a double-group pretest-posttest quasi-experimental design to compare the effects of Problem-Based Learning (PBL) with the traditional mode of science instruction. A total of 85 second-year TVET students participated: 45 in the experimental group (25 males, 20 females) and 40 in the control group (23 males, 17 females), drawn from two institutions in Kpando Municipality. Purposive sampling was used to select the participants to ensure representation from both institutions and balanced gender distribution**.** Data were collected using the Inorganic Compound Nomenclature Proficiency Test (ICNPT) and the Student Perception Questionnaire (SPQ), with established reliability (ICNPT r = 0.75; SPQ α = 0.86). The experimental group received eight weeks of PBL instruction, while the control group received traditional lectures. The instructional topics included binary compounds, polyatomic compounds, oxo salts, and bases. Descriptive statistics, independent-samples t-tests, and Welch's test were used for analysis, with SPSS version 25 employed for all statistical procedures.

4. Results and Discussion

4.1 Analysis of Pretest Results on Achievement Test

Table 1: Students Performance on Inorganic Compound Nomenclature Proficiency Pretest

Mark Range	Control Group (N=40)		Experimental Group (N=45)	
	Frequency	**Percentage (%)**	**Frequency**	**Percentage (%)**
0-9	21	52.5	19	42.2
10-19	18	45.0	18	40.0
20-29	0	0.0	7	15.6
30-39	1	2.5	1	2.3
40-45	0	0	0	0.0

Source: Fieldwork data (2023)

Table 2: Summary of Pretest Achievement Scores on Nomenclature Proficiency Test

Parameter	Control Group	Experimental Group
Mean	10.18	12.38
Standard Error	0.87	0.89
Median	9	11
Mode	8	12

Frequency distribution analysis revealed that the majority of students in both the control and experimental groups scored within the 0–9 and 10–19 ranges. In the control group, 21 students scored between 0–9 and 18 between 10–19, with no scores recorded in the 20–29 or 40–45 ranges and only one student scored between 30–39. In the experimental group, 19 students scored between 0–9 and 18 between 10–19, while seven students attained scores within the 20–29 range and one between 30–39. No student in either group scored above 40. The control group recorded a mean of 10.18 (Median = 9; Mode = 8), while the experimental group obtained a mean of 12.38 (Median = 11; Mode = 12). In both groups, the mean exceeded the median and mode, indicating slight positive skewness. However, approximately 90% of students in both groups scored below 20, reflecting generally low proficiency in inorganic compound nomenclature despite marginally better distribution in the experimental group. Script analysis revealed consistent conceptual difficulties across groups. The most prominent challenges included misapplication of IUPAC rules, incorrect assignment of oxidation states (particularly for transition metals), improper use of Roman numerals for multivalent elements, difficulty determining oxidation numbers in polyatomic compounds (especially oxoacids and oxo salts), and confusion between binary ionic and covalent naming conventions. For example, $Fe(OH)_3$ and Fe_2O_3 were frequently named without specifying oxidation states (e.g., "iron hydroxide" or "iron oxide") instead of Iron (III) hydroxide and Iron (III) oxide. In CuCl, many students incorrectly identified copper as +2 rather than +1, while $MgCl_2$ was sometimes written with unnecessary Roman numerals. Students also miscalculated the oxidation state of sulfur in H_2SO_4, often assigning negative values instead of the correct +6. A fundamental misconception was evident in students' inability to distinguish ionic from covalent compounds. Ionic compounds such as Na_2O and $CaCl_2$ were sometimes named using covalent conventions, while molecular compounds like PCl_5 and CO_2 were named without appropriate prefixes. This confusion suggests weak conceptual understanding of bonding principles underlying nomenclature. These findings align with Baah and Anthony-Krueger (2012), who reported widespread student difficulty in applying IUPAC rules and determining oxidation numbers accurately. Overall, the persistence of these misconceptions across both groups indicates systemic conceptual gaps, thereby justifying the need for targeted instructional interventions such as problem-based learning to improve conceptual clarity and application accuracy.

4.2 Analysis of Posttest Performance of the Experimental and Control Group

Table 3: Students Performance on Inorganic Compound Nomenclature Proficiency Posttest

Mark Range	Control Group (N=40)		Experimental Group (N=45)	
	Frequency	**Percentage (%)**	**Frequency**	**Percentage (%)**
0-9	0	0.0	0	0.0
10-19	29	72.5	4	8.9
20-29	10	25.0	14	31.1
30-39	1	2.5	26	57.8
40-45	0	0	1	2.2

Source: Fieldwork data (2023)

Table 4: Summary of Posttest Achievement Scores on Nomenclature Proficiency Test

Parameter	Control Group	Experimental Group
Mean	17.8	30.22
Standard Error	0.72	1.05
Median	17.5	31.0
Mode	18.0	38.0
Minimum	11.0	15.0
Maximum	31.0	44.0

Table 5: Two-Sample t-test Assuming Equal Variances

	Experimental Group	Control Group
Mean	30.22222222	17.8
Variance	49.54040404	20.98462
Observations	45	40
Pooled Variance	36.12262383	
Hypothesized Mean Difference	0	
Df	83	
t Stat	9.511224649	
P(T<=t) one-tail	3.10081E-15	
t Critical one-tail	1.663420175	
P(T<=t) two-tail	6.20162E-15	
t Critical two-tail	1.98895978	

Alpha level =0.05

Descriptive analysis of posttest scores revealed a clear performance difference between the experimental and control groups. The experimental group, which received problem-based learning (PBL) instruction, obtained a mean score of 30.22 (SD = 7.48), whereas the control group recorded a mean of 17.80 (SD = 4.58). This represents a mean difference of 12.42 points in favour of the experimental group. In addition to the higher mean score, the experimental group demonstrated greater representation in the upper score ranges (20–29 and 30–39), while the majority of control group scores remained concentrated in lower score categories. These descriptive findings suggest that students exposed to PBL achieved stronger mastery of inorganic compound nomenclature compared to those taught using traditional instructional approaches. To determine whether this observed difference was statistically significant, an independent samples t-test assuming equal variances was conducted. The analysis revealed a statistically significant difference in posttest scores, $t(83) = 9.51$, $p < .001$ (two-tailed), at the 0.05 alpha level. Because the calculated t-value substantially exceeded the critical value (1.99), and the p-value was far below the significance threshold, the null hypothesis of no difference between groups was rejected. This indicates that the performance difference was unlikely to have occurred by chance. To assess the magnitude of the difference, Cohen's d was calculated using the pooled standard deviation, yielding an effect size of approximately $d = 2.07$. This represents a very large effect, suggesting that the impact of problem-based learning was not only statistically significant but also educationally meaningful. The size of the effect indicates substantial practical significance in students' learning outcomes. The strong improvement observed in the experimental group can be interpreted through the lens of constructivist learning theory, which posits that learners actively construct knowledge through engagement, inquiry, and problem-solving rather than through passive reception of information. In the PBL environment, students were required to analyze authentic chemical problems, determine oxidation states, differentiate bonding types, justify nomenclature decisions, and collaboratively refine their reasoning. Such engagement likely promoted deeper cognitive processing and conceptual restructuring, particularly in areas previously identified as challenging, including oxidation number assignment and distinguishing between ionic and covalent compounds. From a cognitive perspective, PBL supports meaningful learning by encouraging the integration of new information with prior knowledge structures. The performance gains observed in this study, therefore, suggest that students developed stronger conceptual schemas related to chemical bonding and nomenclature rather than relying solely on memorization of procedural rules. This interpretation is consistent with the meta-analysis conducted by Walker, Leary, and Hmelo-Silver (2018), which reported consistent academic gains associated with PBL across disciplines. Similarly, Duch, Groh, and Allen (2001) found that students in PBL settings demonstrated stronger analytical and problem-solving skills than those in traditional classrooms. Earlier research by Albanese and Mitchell further demonstrated that PBL enhances the application of theoretical knowledge in complex learning contexts.

Although the results strongly support the effectiveness of PBL, alternative explanations should be acknowledged. Differences in instructional enthusiasm (teacher effect) or increased motivation due to exposure to an innovative method (novelty effect) may have contributed to improved performance in the experimental group. However, both groups were taught the same content within the same timeframe and assessed using the same posttest instrument, reducing the likelihood that extraneous factors alone account for the difference. Moreover, the exceptionally large effect size makes it unlikely that temporary motivational influences solely explain the magnitude of improvement. Qualitative script analysis further revealed evidence of conceptual clarification in previously problematic areas, indicating genuine cognitive development rather than superficial engagement. Overall, the posttest findings provide strong evidence that problem-based learning significantly enhanced students' mastery of inorganic compound nomenclature compared to traditional instructional approaches. The difference between groups was statistically significant and associated with a very large effect size, demonstrating both reliability and practical importance. When interpreted within constructivist learning theory and supported by existing empirical research, the results suggest that PBL promotes deeper conceptual understanding and improved application of chemical principles.

Table 6: Perceptions of Experimental Students on the Use of Problem-Based Learning

	Statement	SA F (%)	A F (%)	N F (%)	D F (%)	SD F (%)
1.	PBL enhanced my understanding of inorganic compound nomenclature.	22(48.9)	20(44.4)	2(4.4)	1(2.2)	0(0.0)
2.	Collaborative problem-solving in PBL sessions helped me grasp complex naming concepts.	27(60.0)	16(35.6)	2(4.4)	0(0.0)	0(0.0)
3.	Problem-Based Learning positively influenced my confidence in naming inorganic compounds.	30(66.7)	12(26.7)	2(4.4)	1(2.2)	0(0.0)

4.	Engaging in PBL activities improved my ability to apply naming rules accurately.	23(51.1)	18(40.0)	4(8.9)	0(0.0)	0(0.0)
5.	PBL sessions encouraged me to think critically about complex naming scenarios.	26(57.8)	16(35.6)	2(4.4)	1(2.2)	0(0.0)
6.	The hands-on activities during PBL sessions were engaging and effective.	25(55.6)	18(40.0)	1(2.2)	1(2.2)	0(0.0)
7.	Applying naming rules independently in PBL tasks improved my confidence.	22(48.9)	20(44.4)	2(4.4)	1(2.2)	0(0.0)
8.	PBL activities inspired me to explore various ways of naming inorganic compounds.	24(53.3)	18(40.0)	2(4.4)	1(2.2)	0(0.0)
9.	The collaborative nature of PBL enhanced my understanding of complex naming concepts.	22(48.9)	20(44.4)	2(4.4)	1(2.2)	0(0.0)
10.	The variety of naming scenarios presented in PBL tasks improved my learning experience.	26(57.8)	14(31.1)	3(6.7)	1(2.2)	1(2.2)
11.	I found Problem-Based Learning to be an effective way to learn inorganic compound nomenclature.	22(48.9)	17(37.8)	3(6.7)	3(6.7)	0(0.0)
12.	Problem-Based Learning was an engaging approach to studying inorganic compound names.	19(42.2)	22(44.9)	2(4.4)	2(4.4)	0(0.0)
13.	I believe that Problem-Based Learning improved my naming skills significantly.	25(55.6)	15(33.3)	3(6.7)	1(2.2)	1(2.2)
14.	Problem-Based Learning fostered a deeper understanding of inorganic compound names.	23(51.1)	16(35.6)	3(6.7)	2(4.4)	1(2.2)
15.	I would recommend Problem-Based Learning to other students studying inorganic chemistry.	34(75.6)	9(20.0)	1(2.2)	1(2.2)	0(0.0)

Key: **SA**= Strongly Agree, **A**= Agree, **N**= Neutral, **D**= Disagree, **SD**= Strongly Disagree

Analysis of students' responses indicates a highly positive perception of problem-based learning (PBL) in enhancing understanding of inorganic compound nomenclature. An overwhelming majority (93.3%) agreed that PBL improved their comprehension of complex naming concepts, with 48.9% strongly agreeing and 44.4% agreeing. This suggests that students perceived the approach as effective in clarifying conceptually demanding content. Collaborative problem-solving emerged as a particularly influential component of the PBL process. A total of 95.6% of respondents agreed that group discussions and shared problem analysis enhanced their grasp of complex naming tasks. This strong endorsement highlights the perceived value of peer interaction in unpacking oxidation states, bonding distinctions, and rule application. Only a small minority (4.4%) expressed neutral views, indicating broad acceptance of collaborative engagement as a learning facilitator. Confidence development was another notable outcome. Approximately 93.3% of students reported increased confidence in naming inorganic compounds following participation in PBL activities. Similarly, 91.1% indicated that PBL improved their ability to apply naming rules accurately. These findings suggest that PBL may have strengthened both conceptual clarity and procedural fluency, contributing to improved self-efficacy in chemistry tasks. Students also reported enhanced critical thinking skills, with 93.4% expressing agreement that PBL sessions encouraged analytical reasoning. The structured engagement with diverse naming scenarios (88.9% agreement) and hands-on problem tasks (95.6% agreement) appears to have supported active cognitive processing rather than passive memorization. Although a small proportion of respondents expressed neutral or negative views (ranging between 2.2% and 13.4% depending on the item), these responses indicate areas where differentiated instructional support may be beneficial rather than undermining the overall positive trend.

The findings align with established literature on the effectiveness of PBL. The meta-analysis by Gijbels, Dochy, den Bossche, and Segers (2005) reported that PBL enhances deeper-level understanding and long-term retention of knowledge. Similarly, Shore, Shore, and Broggs (2004) found that PBL fosters intrinsic interest in subject matter. From a cognitive and collaborative standpoint, Pea (1993) argued that distributed cognition within group problem-solving environments strengthens learning through shared expertise. This perspective is reinforced by Rochelle (1996) and Palincsar and Herrenkohl (1999), who emphasize shared meaning-making and internalization of knowledge during collaborative learning, consistent with the socio-cultural framework of Vygotsky (1978), which posits that cognitive development occurs through social interaction within the zone of proximal development. Additionally, the principle of "learning by doing," advocated by Schank, Berman, and Macpherson (1999), supports the hands-on structure of PBL tasks. Active engagement, which King (2008) identifies as critical for meaningful problem discovery, appears to have contributed to students' positive experiences. Broader scholarly consensus, including Camp (1996), Edens (2000), Kaufman (1998), Major and Palmer (2001), and Rhem (1998), underscores the effectiveness of student-centered and self-directed approaches in promoting analytical reasoning and problem-solving competence. Overall, the perception data complement the quantitative achievement results by indicating that students not only performed better under PBL but also experienced increased understanding, engagement, confidence, and critical thinking. The convergence of performance outcomes and learner perceptions strengthens the argument that PBL provides both cognitive and affective benefits in the teaching of inorganic compound nomenclature.

5. Conclusion

The findings of this study demonstrate that Problem-Based Learning (PBL) significantly enhances TVET students' mastery of inorganic compound nomenclature. Students exposed to PBL outperformed their peers taught through traditional lecture-based methods, achieving higher mean scores, deeper conceptual understanding, and improved application of naming principles. Beyond academic achievement, PBL promoted critical thinking, problem-solving skills, collaborative learning, and increased student confidence. The approach also supported equitable learning outcomes across genders, suggesting its potential to reduce performance disparities in science classrooms. Collectively, these results indicate that PBL is a more effective instructional strategy than conventional lecture-based approaches in TVET science and chemistry education. However, these findings should be interpreted within the context of certain limitations. The relatively small sample size and the inclusion of only two TVET institutions in Kpando Municipality may limit the generalizability of the results to other settings. The quasi-experimental design without random assignment means that pre-existing differences between groups cannot be entirely ruled out. Furthermore, the eight-week intervention period may not fully capture the long-term retention effects of PBL, and the use of self-reported perception data may introduce response bias. Finally, the study focused solely on inorganic compound nomenclature, which may limit the applicability of the findings to other chemistry topics or subject areas.

5.1 Recommendations

Based on these findings, the following recommendations are proposed:

i. **Curriculum Integration:** Incorporate PBL strategies systematically into the TVET chemistry curriculum to enhance students' understanding and practical application of chemical nomenclature.
ii. **Teacher Training:** Provide professional development programs for chemistry educators on effective PBL facilitation, including problem design, group management, and assessment strategies.
iii. **Collaborative Learning:** Promote student-centered, collaborative activities that encourage shared problem-solving and active engagement in chemical concepts.
iv. **Future Research:** Investigate technology-enhanced PBL approaches, such as virtual simulations and interactive platforms, and conduct longitudinal studies to examine the long-term impact of PBL on student learning, retention, and career readiness.

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