EFFECT OF INTEGRATING A COOPERATIVE LEARNING MODEL INTO IDEAL PROBLEM-SOLVING INSTRUCTIONAL STRATEGY ON SENIOR SECONDARY SCHOOL STUDENTS' REASONING ABILITY AND ACHIEVEMENT IN MOLE

ZAJES 24(S)2024
p-ISSN:2795-3890
e-ISSN: 2805-3877

Markus Mhya Landas
Department of Chemistry
College of Education Waka Biu
Landa_2009@yahoo.com

The study examines the impact of integrating a cooperative learning model into a problem-solving instructional strategy on senior secondary school students' reasoning ability and achievement in the mole concept in chemistry. The research used a quasi-experimental design and involved four schools in Nigeria. Results showed that the cooperative learning strategy improved reasoning ability, but had limited impact on academic achievement. The weak correlation between reasoning ability and achievement highlights the need for integrating cognitive skills with foundational conceptual understanding. Recommendations include teacher training, curriculum adjustments, and further research to optimize these strategies.

Article History
Received: Oct. 2024
Review processes
Oct - Nov 2024
Received in revised form: Nov 2024
Accepted: Dec 2024
Published online: Dec 2024

KEYWORDS
- Mole concept
- Cooperative Learning
- Problem solving
- Reasoning ability

Introduction:

The teaching and learning of chemistry, particularly at the secondary school level, have long been recognized as challenging due to the abstract nature of many of its concepts. Among these, the mole concept stands out as one of the most complex topics for students to grasp. This difficulty often stems from the abstract and quantitative reasoning required to understand and apply the concept in problem-solving contexts. Despite its foundational importance in chemistry, traditional instructional approaches, such as lecture-based teaching, have frequently proven inadequate in fostering deep understanding, critical reasoning, and long-term retention of the mole concept.

To address these challenges, educators and researchers have explored various pedagogical strategies aimed at enhancing student engagement, reasoning ability, and academic achievement. One promising approach is the integration of cooperative learning models into problem-solving instructional strategies. Cooperative learning, grounded in the theories of social constructivism, emphasizes active student collaboration, positive interdependence, and individual accountability. When combined with structured problem-solving frameworks such as the IDEAL model (Identify, Define, Explore, Act, Look back), this approach has the potential to transform the teaching and learning experience.

This study investigates the effect of integrating a cooperative learning model into the IDEAL problem-solving instructional strategy on senior secondary school students' reasoning ability and achievement in the mole concept in chemistry. The focus is on evaluating how this combined instructional approach enhances students' ability to reason through abstract concepts, solve complex problems, and achieve better academic outcomes. This research addresses the need for innovative teaching strategies in chemistry education and contributes to the growing body of knowledge on effective pedagogical practices for improving learning outcomes in science education.

Statement of the Problem

Despite the critical role of the mole concept in chemistry education, it remains one of the most challenging topics for senior secondary school students to understand and master. Traditional teacher-centred instructional methods, which emphasize rote memorization and procedural learning, often fail to promote the deep conceptual understanding and reasoning ability necessary for solving complex problems associated with the mole concept. Consequently, many students exhibit low achievement and struggle to apply their knowledge in problem-solving contexts. Research suggests that integrating innovative pedagogical strategies, such as cooperative learning models and structured problem-solving frameworks like the IDEAL model, can enhance students' engagement, reasoning ability, and academic performance. However, there is limited empirical evidence on the effectiveness of combining these approaches in teaching abstract and quantitative topics like the mole concept in chemistry.

This study seeks to address this gap by investigating the effect of integrating a cooperative learning model into the IDEAL problem-solving instructional strategy on senior secondary school students' reasoning ability and achievement in the mole concept. The findings aim to provide actionable insights into improving chemistry education and fostering critical thinking and problem-solving skills among students.

Objectives of the study

The main purpose of this study is to determine the effect of integrating a cooperative learning model into the IDEAL problem-solving instructional strategy on secondary school chemistry students' reasoning ability and achievement of the mole concept. Specifically, the study will seek to;

i. Find out the effect of integrating a cooperative learning model into IDEAL problem-solving instructional strategy on senior secondary school chemistry students' reasoning ability on the mole concept in chemistry.

ii. Determine the effect of integrating a cooperative learning model into a problem-solving instructional strategy on senior secondary school chemistry students' achievement of the mole concept in chemistry.

iii. Find out the relationship between senior secondary school students' reasoning ability and their achievement in the mole concept when taught using integrating cooperative learning into IDEAL problem-solving instructional strategy

Literature Review

This research work is based on Bruner, (1966) theoretical framework. A major theme in the theoretical framework is that learning is an active process in which learners construct new ideas or concepts based on their current/past knowledge. The learner selects and transforms information, constructs hypotheses, and makes decisions, relying on a cognitive structure to do so. Constructivism is a theory that is based on observation and scientific study about how people learn. It says that people construct their understanding and knowledge of the world, through experiencing things and reflecting on those experiences. Cognitive structure (i.e., schema, mental models) provides meaning and organization to the experiences and allows the individual to "go beyond the information given".

Constructivism's point of view is that students are not blank slates upon which knowledge is etched. They come to learning situations with already formulated knowledge, ideas, and understandings. This previous knowledge is the raw material for the new knowledge they will create through experiments, asking questions and trying things that don't work. In the actual sense, learning activities require the student's full participation (like hands-on experiments). An important part of the learning process is that students reflect on and talk about their activities. Students also help set their own goals and means of assessment. They control their learning process, and they lead the way by reflecting on their experiences.

However, the difficulty is not an intrinsic characteristic of a problem because it depends on the solver's knowledge and experience so a problem may be genuine for one individual but may not be for another (Schunk, 2000). Problem-solving therefore is seen as a model of complex cognition that is part of our everyday experience.

Studies have supported the view that the interplay between macroscopic and microscopic worlds is a source of difficulty for many chemistry learners. A few examples include; chemical bonding (Taber, 2002; Taber & Coll, 2003; Coll & Treagust, 2003; Özmen, 2004), and solution chemistry. Chemistry, by its very nature, is highly conceptual, and students may learn names as well as definitions of chemical substances theoretically by rote learning (this often being reflected by efficient recall in examination questions) but true mastery of the chemical reactions has not been attained. As a matter of fact, chemistry certainly is full of abstract concepts that are perceived as difficult to beginners at colleges or degree levels. Hence real understanding demands the bringing together of conceptual understandings in a meaningful way right from the secondary school level. To this effect, the attention of many science educators has continued to be directed at searching for appropriate methods of science instruction. Researchers like Fajola, (2007) have focused on several dynamic and pragmatic teaching methods and strategies such as problem-solving, projects, field trips, concept mapping, and computer instruction as a way forward. Also Salami, (1991) states that mastery learning strategy and individualised programmed instruction respectively have been used by researchers in their bid to improve students' achievement in different science subjects.

In chemistry for instance stoichiometry is a study of the quantity of a substance that was involved in the chemical reaction. It lays the foundation for the understanding of the number of substances that will react in a definite proportion and demands proportional reasoning skills on the part of learners. As such, an understanding of the principles of stoichiometry has an important place in chemistry learning. To understand the stoichiometry of reactions and solve problems in this area, students need to know atomic masses, chemical formulas of substances that are involved in a reaction, as well as an understanding of the law of conservation of mass.

Besides the main language which influences science understanding is the application of mathematics to chemistry in these topics and no meaningful learning could be done without adequate knowledge of mathematics in chemistry and science in general (Chiu, 1993). He further stressed that science being mathematically based has made it so unpopular among students at both secondary school and college levels. Furthermore, (Adeoye, 2000), stated that problem-solving is a prominent feature in the learning of science and neglecting it could hurt students' learning outcomes in the sciences as a result students see chemistry as a subject and its teaching as unpopular and repelling. In light of this, the knowledge of how teaching methods affect students' learning will help educators select methods that will improve teaching quality, effectiveness, and accountability to learners and to society.

To address this issue many problem-solving models have been proposed to teach the different aspects of science. To this effect, an enhanced knowledge of the conditions for effective learning based upon which a range of student-centred teaching methodologies, such as cooperative learning, problem-solving, inquiry etc have become the latest thing but little guidance as to how teachers might apply these to the teaching of particular chemistry topics such as reaction kinetics, mole concept, molar volume or stereochemistry.

In teaching through problem-solving students learn and understand important aspects of the concept or idea by exploring the problem situation as most of the problems used tend to be more open-ended and allow for multiple correct answers and multiple solution approaches. Actually, it could be said that in this approach, problems do not only form the organizational focus and stimulus for students' learning, but they also serve as a vehicle for mathematical exploration and manipulation as most of the chemistry problems are quantitative.

Problem-solving has been defined in various ways. Dewey, (1938) states that a problem is anything that gives rise to doubt and uncertainty. Also, problem-solving can be seen as a way of thinking in which a learner discovers a combination of previously learned rules that he can use to solve an unusual problem. Ausubel (1969) opined that problem-solving is a form of discovery learning in which the gap between a learner's existing knowledge and the solution to the problem is bridged. Thus, somewhere between open-ended, creative thinking and the focused learning of content, lies the problem-solving.

Problem-solving is viewed as a fundamental part of learning science in regular schools (Yerushalmi & Magen, 2006; Loucks, 2007) after the instructor introduces the concepts, students apply these concepts to the problems. Problems in this context should follow some well-defined criteria: all information needed to solve the problem should be given; a limited set of rules is needed to solve the problem; in many cases, only one procedure leads to the right answer; and there is only one correct answer.

Generally speaking, a problem is any situation or matter that is challenging to solve, thus requiring one to make a difficult decision. The decision to make can be about anything; how to answer a perplexing question, how to handle a complicated situation, how to convince someone to see one's point of view, or even how to solve a puzzle or mystery. Every problem has at least three components: givens, goals, and operations. The givens are the facts or pieces of information presented to describe the problem, the goal is the desired end state of the problem and operations are the actions to be performed in reaching the desired goal. Based on how the problem and the goal are represented. Problems are categorized as ill or well-defined problems i.e. those with complex representations and/or more than one solution are termed ill-defined while the ones with discrete representations and finite goals are termed well-defined. The distinction between ill-defined and well-defined problems is a continuum, depending on the complexity of the problem and what is required of mental tasks to solve it.

Clough (1997) suggests that intuition; creativity, imagination, serendipity, aesthetics, and logic all play a role in solving problems. Solving chemistry problems then requires the students to possess conceptual knowledge, procedural knowledge, and the ability to translate the language of the problem to decode its real meaning. The problem solver in this way creates a cognitive structure according to the problem. The ability of the solver to understand the language of the problem is the first step towards successful problem-solving; this is followed by the separation of the relevant and the irrelevant data, identifying the variables that are involved, and the nature and structure of the problem as being either an open-ended solution or a multiple choice problem. From the foregoing problem-problem-solving in science largely depends on the student's cognitive ability level as a pivot for meaningful and retentive learning. More so**,** in problem-solving, it is thought that working memory is utilized to process information about the problem and maintains its availability during the problem-solving process. Since working memory has limited storage capacity, it is impossible for information in a problem to exceed the working memory limit and to interfere with attempts to seek a solution. If one is to use short-term memory in problem-solving, it is required that relevant information from the solvers' previous knowledge base about the problem be accessed and retrieved from the storage of long-term memory.

Chemical changes that do occur always involve discrete numbers of atoms that rearrange themselves into new configurations. These are huge numbers of atoms far too large in magnitude to be able to count or even to visualise (Atkins, Peter, and Jones, Loretta, 2002). However, they are still numbers so useful in the study of chemistry particularly in the understanding of the quantitative aspect of it. Therefore, there is a need to have a way to count them and also a way to bridge these numbers which cannot be measured directly with the weight of substances which we can measure and observe.

The mole fits into this gap and is central to all of the quantitative chemistry. In chemistry, the mole is a fundamental unit in the Système International d'Unités, the SI system, and it is used to measure the amount of substance. This quantity is sometimes referred to as the chemical amount. In Latin mole means a "massive heap" of material. The mole therefore is the SI measure of quantity of a "chemical entity'' which can be an atom, molecule, formula unit, electron photon etc (Lide, (2000). Hence one mole of anything is just Avogadro's number of that thing (1mole = 6.022×10^{23}). For example, one mole of Oxygen gas (O_2) contains about 6.022×10^{23} molecules of Oxygen, has a mass of 31.998 grams, and occupies a volume of 22.4 L at standard temperature and pressure (STP; 0°C and 1 atm).

As one of these quantities is measured it allows the calculation of the others and this is frequently done in stoichiometry which is the study of the quantitative relationship between reactants and the products. The reactants and the products are represented by the use of symbols either as atoms, molecules, compounds etc. For the fact that atoms and molecules are incredibly small, and even a tiny chemical sample contains an unimaginable number of them. Therefore, counting the number of atoms or molecules in a sample is impossible.

The mole allows chemists to bridge the gap between the sub-microscopic world of atoms and molecules and the macroscopic world that we can observe. As a result, chemists generally relate moles of a substance to mass rather than to the number of particles. Hence to determine the mole of a sample the molar mass of the substance is used i.e mass per mole of particle. Due to this fact problem - solving is essential to the understanding of the mole concept. It is such that suitable as its application deals with the quantitative relationship between reactants and products in a chemical reaction. Its usage involves a variety of permutations (moles to grams, the volume of gas at STP to mass, molecules to moles, etc.) when solving mole problems. The mole plays a significant role in mole-mass and mass-mole conversions, per cent composition problems, and the concept of empirical, molecular and formula problems.

Therefore, a good knowledge in mathematics is a favourable companion for one to be successful in the calculations involving the conversions stated above. No doubt any student who cannot reason proportionally will have difficulty in understanding equations, functional relationships between molality, molarity, concentration in grams, concentration in grams per dm^3 and topics such as stoichiometry, empirical and molecular formula which all have direct or indirect relationships with the mole.

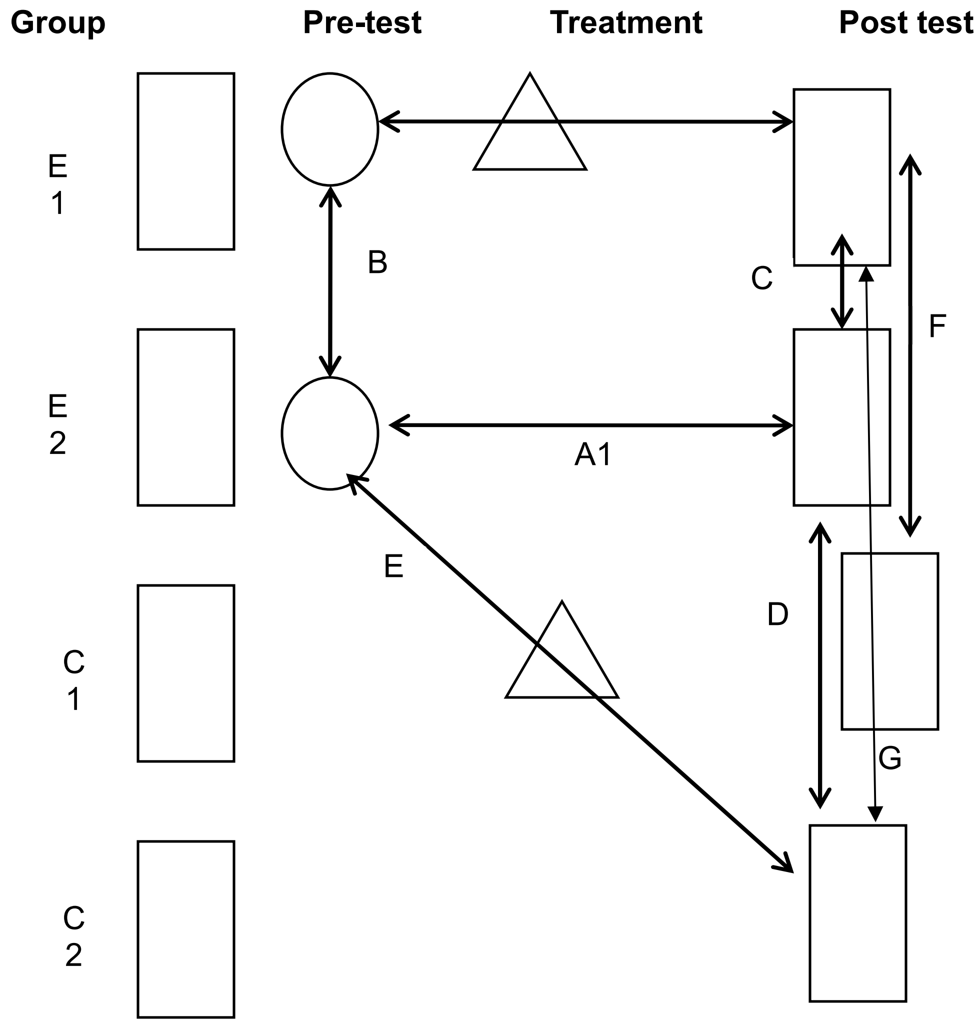
Methodology

The study will be quasi-experimental using the Solomon Four Group Design. The Solomon four-group experiment design is a standard pre-test post-test two-group design and a post-tests-only control design. This design contains two extra control groups, which serve to reduce the influence of confounding variables, and extraneous factors and allow the researcher to test whether the pretest itself affects the subjects. It combats many of the internal validity issues that can plague research such as history, maturation, testing and instrumentation. It allows the researcher to exert complete control over the variables and allows the researcher to check that the pretest did not influence the results by the use of various combinations of tested and untested groups with treatment and control groups. (Trochim, 2008) See the schematic diagram of the design in Figure 3.1.

In the figure, E, E1, C and C1 are the same as in the standard two-group design. The first two groups of the Solomon four-group design are designed and interpreted in the same way as in the pre-test-post-test design, and provide the same checks upon randomization. The comparison between the post-test results of groups E1 and C2, marked by line 'G', allows the researcher to determine if the actual act of pretesting influenced the results. If the difference between the post-test results of Groups E2 and C2 is different from the Groups E1 and E2 marked by line ‘C’ then the researcher can assume that the pre-test has had some effect on the results The comparison between the Group E2 pre-test and the Group C2 post-test marked by line ‘E’ allows the researcher to establish if any external factors have caused a temporal distortion. For example, it shows if anything else could have caused the results shown and is a check upon causality. The Comparison between Group E1 post-test and the Group C1 post-test marked by line “F” allows the researcher to determine the effect that the pre-test has had upon the treatment. If the post-test results for these two groups differ, then the pre-test has had some effect on the treatment and the experiment is flawed. The comparison between the Group E2 post-test and the Group C2 post-test marked by line “D” shows whether the pre-test itself has affected behaviour, independently of the treatment. If the results are significantly different, then the act of pre-testing has influenced the overall results and needs refinement.

.

Fig 1 Solomon four group design



This study is set to find out the effect of integrating cooperative instructional strategy into problem-solving instruction strategy on senior students' achievement and reasoning ability on the mole concept in chemistry. The cooperative learning that will be used is the team, pair-solo strategy. The school's regular chemistry teachers are used in the teaching of the contents to be covered for the study. Both the experiment and control groups are taught the same selected topics under similar conditions; that is the same number of periods and hours of the day. Before the experiment takes off, Group E1 and Group E2 are given pre test examinations on both the chemistry achievement test (CAT) and test of logical thinking (TOLT). The experiment lasted for four weeks and by the end of the fourth week a post-test was administered to all the groups; E1, E2, C1, and C2 respectively. The pre-test and post-test scripts are marked, scored, recorded and analysed.

The study area is Borno State which is one of the thirty-six geopolitical administrative states in Nigeria. Borno State is a state in the Northeast geopolitical zone of Nigeria, bordered by Yobe to the west, Gombe to the southwest and Adamawa to the south while its eastern border forms part of the national border with Cameroon for about, its northern border forms part of the National border with Niger, and its northeastern border forms all of the national border with Chad Coordinates.

The population for the study is all of the Senior Secondary School three (SSIII) students offering chemistry in the public schools in the southern Borno educational zone. The choice of SS3 chemistry students is because the students were assumed to have acquired a rudimentary knowledge of mole concepts in chemistry. The researcher used only four out of ten secondary schools that offer chemistry in this education zone.

A random sample from the schools was made, and a similar procedure is used in assigning the schools into pretest-post test experiment group and two post-assessment control groups. Where there are more than one chemistry class in the school selected, the process above is repeated to select a class as the experiment will be an intact class.

For this study, two instruments are used for data collection. These are the Test of Logical Thinking (TOLT) and Chemistry Achievement Test (CAT). The Test of Logical Thinking (TOLT), which originally was developed by Tobin and Capie (1981), will be adopted and used to determine the formal reasoning ability of SSIII chemistry students. Although the original test has two versions (A and B) which were developed to provide parallel group testing, however the TOLT, form A is chosen and adopted for the present study. The reason for the choice of this form of the TOLT was because of its reliability and validity results reported by Tobin and Capie (1980, 1981) when they administered it on samples of students ranging from sixth grade (equivalent SSSIII) to college level. The researcher feels it is appropriate to administer similar to SSIII students whom soon their next level of education pursuit is either Universities, Polytechnics or Colleges of various kinds.

The researcher visits the schools that are selected for this research work together with the help of the schools' chemistry teachers who were trained to be research assistants for the study and administered the instruments to the students where data for the study was collected through their responses to the two instruments the CAT and the TOLT simultaneously.

The data collected for the study was analysed using ANOVA, mean, standard deviation, t-test and Pearson's Moment Correlation coefficient. Research questions 1 and 2 as well as hypotheses 1 and 2 were answered and tested using mean, standard deviation, and t-test while research questions 3 and hypotheses 3 were answered and tested with Pearson's Moment Correlation coefficient at 0.05 confidence level respectively.

Results

Here the result of the study is presented in a tabular form according to the hypotheses. At the end of the presentation, a summary of the results was made.

Hypothesis 1 There will be no significant difference between the mean post-test score on the achievement of students taught mole concepts using integrating a cooperative learning model into IDEAL problem-solving instructional strategy and those taught using the lecture method.

Table 1: Showing the Mean scores of the groups of Participants on Chemistry Achievement and Logical Thinking

	Groups	M	SD	N
CA post-test scores	(E1)	22.9174	10.78006	121
	(E2)	20.5207	11.37402	121
	(C1)	23.3058	9.39667	121
	(C2)	23.2066	11.39877	121
	Total	**22.4876**	**10.79557**	**484**
LOT post-test scores	(E1)	24.1983	9.19658	121
	(E2)	12.1322	7.25941	121
	(C1)	17.8182	6.20752	121
	(C2)	18.4959	8.61696	121
	Total	**18.1612**	**8.96779**	**484**

Source: Field Survey 2024

The results of the post-test scores for **Chemistry Achievement** and **Logical Thinking** as presented in Table 1 reveal some interesting trends regarding the effectiveness of the experimental treatments. In **Chemistry Achievement**, the **experimental groups (E1 and E2)** generally scored lower than the **control groups (C1 and C2)**, with **E1** showing the highest mean among the experimental groups (22.92), but still trailing behind the control groups, which scored around 23.2. This suggests that the experimental interventions may not have had a significant positive effect on chemistry performance. The high **standard deviations** in the experimental groups (particularly in E2) indicate considerable variability, implying that while some students in E1 may have benefitted from the intervention, others may have experienced little improvement or even worse outcomes. In contrast, the **control groups** performed relatively better, with more consistent results, indicating that the intervention may not have been as effective as expected.

In **Logical Thinking**, the results were more polarized. **E1** performed **significantly better** than the other groups (mean = 24.20), suggesting that this particular experimental treatment effectively enhanced logical reasoning skills. However, **E2** had a **much lower mean (12.13)**, significantly underperforming compared to all other groups, which raises concerns about the effectiveness or possible adverse impact of the intervention in this group. The **control groups** (C1 and C2) showed moderate and consistent performance in logical thinking, with scores around 17.8 to 18.5, signifying that if they had been exposed to the experimental treatments they could have performed reasonably well. These findings highlight the effectiveness of the experimental treatments, though not so glaring on the chemistry achievement but had improved their reasoning ability. Thus, the alternative hypothesis is accepted.

Table 2: Showing the differences between the groups in terms of their performance on both Chemistry Achievement and Logical Thinking tests.

Effect		Value	F	Df	Error df	Sig.
Intercept	Pillai's Trace	.906	2317.628b	2	479	.000
	Wilks' Lambda	.094	2317.628b	2	479	.000
	Hotelling's Trace	9.677	2317.628b	2	479	.000
	Roy's Largest Root	9.677	2317.628b	2	479	.000
Groups	Pillai's Trace	.236	21.414	6	960	.000
	Wilks' Lambda	.765	22.873b	6	958	.000
	Hotelling's Trace	.306	24.338	6	956	.000
	Roy's Largest Root	.300	48.063c	3	480	.000

Source: Field Survey 2024

The results of the **multivariate tests** presented in Table 2 provide evidence for the significance of both the **intercept** and the **grouping factor** in explaining the variance in the dependent variables (Chemistry Achievement and Logical Thinking post-test scores). For the **intercept**, all the multivariate statistics—**Pillai's Trace**, **Wilks' Lambda**, **Hotelling's Trace**, and **Roy's Largest Root**—indicate a very strong significance (p = .000), suggesting that there is a significant overall effect of the intercept (the mean levels) across the groups. This implies that there is a substantial baseline effect, or difference, between the groups when accounting for both dependent variables. Similarly, for **Groups**, all tests again show statistically significant results (p = .000), indicating that there are significant differences between the groups in terms of their performance on both Chemistry Achievement and Logical Thinking tests. These results suggest that the grouping variable (which likely refers to the experimental and control groups) has a meaningful impact on the scores across the two outcome variables.

Table 3: The Tests of Between-Subjects Effects showing the variability in the Chemistry Achievement post-test scores and Logical Thinking post-test scores

Sources	Dependent Variable	SS	df	M	F	Sig.
Corrected Model	CA post-test scores	634.033[a]	3	211.344	1.823	.142
	TOLT post-test scores	8836.058[b]	3	2945.353	47.114	.000
Intercept	CAT post-test scores	244755.074	1	244755.074	2110.834	.000
	TOLT post-test scores	159636.570	1	159636.570	2553.558	.000
Groups	CAT post-test scores	634.033	3	211.344	1.823	.142
	TOLT post-test scores	8836.058	3	2945.353	47.114	.000
Error	CAT post-test scores	55656.893	480	115.952		
	TOLT post-test scores	30007.372	480	62.515		
Total	CAT post-test scores	301046.000	484			
	TOLT post-test scores	198480.000	484			
Corrected Total	CAT post-test scores	56290.926	483			
	TOLT post-test scores	38843.430	483			

Source: Field Survey 2024

The results of Tests of Between-Subjects Effects presented in Table 3 provide an analysis of how different sources contribute to the variability in the dependent variables—Chemistry Achievement post-test scores and Logical Thinking post-test scores—across the four groups (Experimental and Control groups). For Chemistry Achievement, the Corrected Model (which includes the groups as the factor) shows a non-significant result (F = 1.823, p = .142), indicating that the grouping factor does not significantly explain the variation in Chemistry Achievement scores. This suggests that the experimental interventions did not have a statistically significant effect on Chemistry achievement when compared to the control groups. The R-squared value for Chemistry Achievement is 0.011, indicating that only 1.1% of the total variation in Chemistry Achievement scores can be explained by the group membership, which is very low and further suggests minimal impact from the interventions.

In contrast, the Logical Thinking post-test scores show a highly significant result (F = 47.114, p = .000), with a substantial effect from the grouping factor. This indicates that the experimental interventions had a significant effect on students' logical thinking abilities. The R-squared value for Logical Thinking is 0.227, meaning that 22.7% of the variation in Logical Thinking scores can be attributed to group membership. This is a considerably higher proportion than in Chemistry Achievement, suggesting that the experimental treatments had a more meaningful impact on improving students' logical thinking skills. The significant F-statistics for the intercepts (both p = .000) for both dependent variables show that the baseline differences between the groups are substantial, with the logical thinking scores showing much stronger effects from the interventions compared to the chemistry scores.

Table 4: LSD Post-hoc-test showing individual group comparison on logical thinking

DV	(I) Groups	(J) Groups	Mean Difference (I-J)	Sig.
TOLT post-test scores	(E1)	(E2)	12.0661*	.000
		(C1)	6.3802*	.000
		(C2)	5.7025*	.000
	(E2)	(E1)	-12.0661*	.000
		(C1)	-5.6860*	.000
		(C2)	-6.3636*	.000
	(C1)	(E1)	-6.3802*	.000
		(E2)	5.6860*	.000
		(C2)	-.6777	.505
	(C2)	(E1)	-5.7025*	.000
		(E2)	6.3636*	.000
		(C1)	.6777	.505

Source: Field Survey 2024

The results presented in Table 4 for **Logical Thinking** show several significant differences. **Experimental Group 1 (E1)** outperformed both **E2** (mean difference = 12.0661, p = .000) and the control groups (**C1** and **C2**, mean differences of 6.3802 and 5.7025, respectively, both p = .000). This suggests that **E1** benefited significantly from the intervention and performed much better than the other groups in logical thinking. **E2**, on the other hand, showed consistently poor performance compared to **E1** and the control groups, with significant negative mean differences across all comparisons (e.g., **E2 vs. C1**, mean difference = -5.6860, p = .000; **E2 vs. C2**, mean difference = -6.3636, p = .000). The **control groups** (**C1** and **C2**) did not significantly differ from each other in their logical thinking scores (p = .505), but they both performed worse than **E1** and better than **E2**. These results indicate that the interventions had a substantial and positive effect on **E1**'s logical thinking skills, but **E2** experienced a significant decline, suggesting that the intervention for **E2** was either ineffective or possibly harmful.

***Ho₂** There will be no significant difference between post-test reasoning ability means score of students taught using integrating a cooperative learning model into IDEAL problem-solving instructional strategy and those taught using lecture method.*

Hypothesis 2

Table 5: One-way ANOVA showing differences in the groups of participants on logical thinking

Sources	SS	df	MS	F	Sig.
Between Groups	8836.058	3	2945.353	47.114	.000
Within Groups	30007.372	480	62.515		
Total	38843.430	483			

Source: Field Survey 2024

The significant **F-value** (47.114, p = .000) results presented in Table 5 confirm that the group membership significantly affects logical thinking performance, with **E1** outperforming the other groups and **E2** performing the worst. The large F-value between-group variance relative to within-group variance suggests that the differences between the groups are substantial and not due to random chance, confirming that the experimental interventions had a measurable impact on logical thinking.

***Ho₃** There will be no significant relationship between the post-test reasoning ability means score and achievement on the mole concept test of students taught using integrating a cooperative learning model into IDEAL problem-solving instructional strategy and those taught using the lecture method.*

Hypothesis 3

Table 6: Pearson Correlation Matrix showing relationships among study variables

		1	2	3	4	5	6	7	8
1	E1 TOLT Post-test scores								
2	E2 TOLT Post-test scores	-.105							

3	C1 TOLT Post-test scores	-.052	.075						
4	C2 TOLT Post-test scores	.023	-.143	-.014					
5	E1 CAT post-test scores	.125	.196*	.124	.028				
6	E2 CAT post-test scores	.216*	-.110	.099	-.061	-.010			
7	C1 CAT post-test scores	.005	-.092	.045	-.082	.215*	-.098		
8	C2 CAT post-test scores	-.081	.017	.079	-.046	.069	-.073	.080	-

***. Correlation is significant at the 0.05 level (2-tailed).**

Source: Field Survey 2024

Table 6 presents the Pearson correlation coefficients for various post-test scores on logical thinking and chemistry achievement across four groups: E1, E2, C1 and C2. These correlations provide insights into how students' performance in logical thinking relates to their achievement in chemistry. When examining the logical thinking scores, the correlation between E1 logical thinking and the other variables is generally weak. E1 logical thinking scores show a small positive correlation with E1 Chemistry Achievement scores (r = 0.125), but this is not statistically significant (p = 0.170). Similarly, the correlation between E1 logical thinking and the logical thinking scores of the other groups (E2, C1, and C2) are very low, with none being statistically significant. The weakest correlation is between E1 logical thinking and C2 logical thinking (r = 0.023, p = 0.799). These findings suggest that E1 logical thinking does not strongly relate to logical thinking performance in other groups or to chemistry achievement.

On the other hand, E2 logical thinking scores show a few significant correlations. There is a significant positive correlation with E1 Chemistry Achievement scores (r = 0.216, p = 0.017), indicating that higher E2 logical thinking scores are associated with better performance in E1 chemistry. There is also a significant negative correlation with C1 Chemistry Achievement scores (r = -0.215, p = 0.018), suggesting that higher logical thinking scores in E2 might be linked to lower achievement in C1 chemistry. However, the correlation between E2 logical thinking and other logical thinking variables (such as C1 and C2 logical thinking) is weak, with no other significant results.

In terms of C1 and C2 logical thinking post-test scores, the correlations with other variables are mostly insignificant. For example, the correlation between C1 logical thinking and C2 logical thinking is near zero (r = -0.014, p = 0.879), showing no meaningful relationship. Other correlations involving C1 and C2 logical thinking with chemistry achievement scores are also weak and not statistically significant.

Looking at the chemistry achievement scores, the relationships are somewhat stronger in certain cases. E1 Chemistry Achievement scores show a significant positive correlation with E2 logical thinking scores (r = 0.216, p = 0.017), reinforcing the idea that better logical thinking in the E2 group correlates with higher achievement in chemistry. However, the correlation between E1 chemistry achievement and C1 chemistry achievement is also significant (r = 0.215, p = 0.018). This suggests that students who perform well in E1 chemistry are also likely to perform well in C1 chemistry. Despite these significant correlations, many other chemistry-related correlations are weak, and several, like those between E1 and E2 chemistry achievement or C1 and C2 chemistry achievement, are not statistically significant.

Overall, the results suggest that there are some meaningful, albeit weak, relationships between logical thinking and chemistry achievement. The strongest correlations appear between E2 logical thinking and E1 chemistry achievement as well as between E1 chemistry achievement and C1 chemistry achievement. However, most correlations are relatively weak, and many are not statistically significant, indicating that the relationship between logical thinking and subject-specific achievement is complex and may vary depending on the specific group and test.

Discussion of Findings

The study's findings underscore the transformative potential of integrating cooperative learning models with the IDEAL problem-solving instructional strategy in enhancing students' reasoning ability and achievement in the mole concept in chemistry. It was observed that the intervention significantly improved reasoning skills, particularly in Experimental Group 1 (E1), which outperformed all other groups in logical thinking tests. This suggests that the collaborative and structured nature of the instructional strategy facilitated critical thinking, peer learning, and reflective problem-solving. These findings are consistent with constructivist theories, such as Bruner's (1966), which emphasize active engagement and collaboration as pivotal to developing higher-order cognitive skills.

However, the study also revealed that the intervention had a less pronounced effect on students' achievement in chemistry, with no statistically significant differences observed between experimental and control groups. The high variability in performance within the experimental groups, particularly in Experimental Group 2 (E2), highlights potential inconsistencies in the implementation of the strategy, differences in group dynamics, or variations in students' readiness to adopt the instructional approach. These findings align with empirical studies, such as those by Taber (2002) and Coll and Treagust (2003), which emphasize the importance of consistent facilitation and foundational readiness in achieving desired outcomes through cooperative learning.

Moreover, the weak correlation between reasoning ability and achievement suggests that while the instructional strategy fosters critical thinking, its impact on mastering abstract and quantitative topics like the mole concept is not direct. This reflects Chiu's (1993) argument that success in chemistry requires not only reasoning skills but also a strong foundation in mathematical and conceptual understanding. The study's results highlight the complex interplay between cognitive skills and content mastery, underscoring the need for a multifaceted approach that integrates reasoning development with effective teaching of foundational concepts.

In conclusion, the findings affirm the potential of innovative teaching strategies in enhancing reasoning ability and highlight their limitations in improving subject-specific achievement without addressing underlying challenges such as mathematical competency and conceptual clarity. These insights call for further research into optimizing the implementation of cooperative and problem-solving strategies, alongside curricular adjustments that balance cognitive and content-focused learning objectives. This dual emphasis could pave the way for more effective teaching of abstract and quantitative topics in chemistry and other sciences.

Conclusions

The following conclusions were made:

1. **Enhanced reasoning ability:** The integration of a cooperative learning model into the IDEAL problem-solving instructional strategy significantly improved students' reasoning abilities, as evidenced by the superior logical thinking scores of Experimental Group 1 (E1) compared to other groups.
2. **Limited impact on chemistry achievement:** The instructional strategy had a limited impact on student's achievement in the mole concept, with no statistically significant differences observed between the experimental and control groups in chemistry achievement post-test scores.
3. **Variability in effectiveness across groups:** There was notable variability in the outcomes among experimental groups, with Experimental Group 2 (E2) underperforming in logical thinking compared to both E1 and the control groups. This suggests inconsistencies in the implementation or contextual factors affecting the strategy's success.
4. **Weak correlation between reasoning ability and achievement:** The weak correlation between reasoning ability and chemistry achievement indicates that improvements in logical reasoning do not necessarily translate into better performance in subject-specific tasks like solving mole concept problems.
5. **Influence of foundational knowledge:** The findings highlight the importance of foundational competencies, such as mathematical skills and conceptual understanding, as prerequisites for success in abstract and quantitative topics like the mole concept.
6. **Need for consistent implementation:** The study emphasizes the importance of well-structured and consistent implementation of innovative teaching strategies to achieve optimal outcomes in both reasoning ability and academic achievement.
7. **Potential of student-centred approaches:** The study affirms the potential of student-centred, collaborative, and problem-solving approaches in fostering higher-order cognitive skills but suggests that these approaches require refinement to address specific challenges in chemistry education effectively.

Recommendations

1. **Improving reasoning ability in chemistry:** Teachers should adopt and implement the integration of cooperative learning models with the IDEAL problem-solving instructional strategy to enhance students' reasoning abilities. To maximize effectiveness, teacher training programs should focus on how to facilitate group activities, encourage critical thinking, and create an interactive learning environment that promotes logical reasoning in challenging topics like the mole concept.
2. **Enhancing academic achievement in the mole concept:** Instructional strategies should address the specific challenges students face in mastering the mole concept by combining cooperative learning and problem-solving with foundational reinforcement in mathematics and chemistry concepts. Incorporating visual aids, real-world applications, and hands-on experiments can make the abstract nature of the mole concept more relatable and enhance students' academic performance.
3. **Strengthening the relationship between reasoning ability and achievement:** Teachers should design lessons and assessments that integrate reasoning skill development with content mastery to create a stronger connection between students'

logical thinking and academic achievement. Collaborative problem-solving tasks, guided discussions, and reflective learning activities should be emphasized to help students apply their reasoning skills in solving complex problems in chemistry effectively.

Acknowledgement

The Tertiary Education Trust Fund (TETFUND) Federal Republic of Nigeria supported the research work. It was financially supported by the IBR TETFund Research Project (Batch-04 2024).

References

Abazov, R. (2016). How to improve your problem-solving skills. Available at: https://www.researchgate.net/publication/305062877_How_to_Improve_Your_Problem-Solving_Skills. (Accessed January 19, 2023).

Adeoye, F. A. (2000). Assessment Procedure, Students' Cognitive Style and Gender as Determinants of Physics Performance of Cognitive Level of Thinking. *Journal of Educational Research*, 5(1), 39-49.

Atkins, Peter, and Jones, Loretta (2002). *Chemical Principles*, 2nd edition. New York: W. H. Freeman and Company

Ausubel, D.P., Robinson HYPERLINK "https://en.wikipedia.org/wiki/Floyd_G._Robinson". (1969). *School Learning: An Introduction to Educational Psychology*. New York: Holt, Rinehart & Winston.

Clough, M.P. (2000). *The unnatural nature of science: Implications for science education*. Paper presented at the Association for the Education of Teachers in Science International Conference, Akron, OH. January 6-9.

Coll, R. K. & Treagust, D. F., (2003). Investigation of Secondary School, Undergraduate and Graduate Learners' Mental Models of Ionic Bonding, *Journal of Research in Science Teaching,* 40(5), 464–486.

Dewey, J. (1938). **Experience and Education**. New York, NY: Collier.

Ebenezer, J. V., (2001). A Hypermedia Environment to Explore and Negotiate Students' Conceptions: Animation of The Solution Process of Table Salt, *Journal of Science Education and Technology,* 10(1), 73–92.

Fajola, O.O (2000) Effects of three modes of computer-based instructional strategies on students
learning outcome in biology. Unpublished

Friedel, A and Maloney, D "An Exploratory, Classroom-Based Investigation of Students Difficulties with Subscripts in Chemical Formulas," *Science Education, 76(1):65-78(1992).*

Grauwe, A. D. (1999). The challenges for the school of the future: *International Institute for Educational Planning, XVII* (4), 10 and 11.

Laurens, T., Batlolona, F. A., Batlolona, J. R., and Leasa, M. (2018). How does realistic mathematics education (RME) improve students' mathematics cognitive achievement? *Eurasia J. Math. Sci. Technol. Educ. 14, 569–578. doi: 10.12973/ejmste/76959*

Lide, D. R., ed. (2000). The CRC Handbook of Chemistry *&* Physics, *81st* edition. New York: CRC Press.

Loucks A.B. (2007). *Low energy availability in the marathon and other endurance sports: 37(4-5):348-52*

Mandina, S., and Ochonogor, C. (2018). Comparative effect of two problem-solving instructional strategies on students' achievement in stoichiometry. *Eurasia J.*

Math. Sci. Technol. Educ. 14, 1–9. doi: 10.29333/ejmste/95125

Melawati, O., Evendi, E., Halim, A., Yusrizal, Y., and Elisa, E. (2022). The influence of the use of student worksheets to increase problem-solving skills and learning outcomes. *Jurnal Penelitian Pendidikan IPA 8:2022. doi: 10.29303/jppipa.v8i1.1205*

Oliveri, M. E., Lawless, R., and Molloy, H. (2017). A literature review on collaborative problem solving for college and workforce readiness. ETS Res. Rep. Ser. 2017, 1–27. doi: 10.1002/ets2.12133

Özmen, H., (2004). Some Student Misconceptions in Chemistry: A Literature Review of Chemical Bonding, *Journal of Science Education and Technology,* 13(2), 147–159.

Ravialo, A., (2001). Assessing Students' Conceptual Understanding of Solubility Equilibrium, *Journal of Chemical Education,* 78(5), 629–631.

Reid, N and Yang, M.J. (2002). The solving of problems in chemistry: the more open-ended problems. *Research in Science & Technological Education*, 20, 83-98.

Salami, A. (1992). *Secondary education programme under the national policy on education.* An assessment based on the WAEC senior secondary school certificate examination paper presented at the WAEC monthly seminar 28th August.

Schunk, D. H. (2000). Learning theories: an educational perspective. New Jersey: Prentice-Hall.

Sutarmi, K., and Suarjana, I. M. (2017). Peningkatan hasil belajar siswa menggunakan metode problem solving dalam pembelajaran. *Jurnal Ilmiah Sekolah Dasar 1, 75–82. doi: 10.23887/jisd.v1i2.10141*

Tabar, K. S., (2002). Alternative Conception in Chemistry: prevention, Diagnosis and Cure.London: *The Royal Society of Chemistry*.

Taber, K. S. & Coll, R. K., (2003). Bonding, in: J. K. Gilbert, O. De Jong, R. Justi, D. F.Treagust & J. H. Van Driel (Eds) *Chemical Education*: Towards Research-Based Practice. Dordrecht: Kluwer.

Trochim, W. M. K., & Donnelly, J. P. (2008). The research methods knowledge base. Mason, Ohio, USA: Atomic Dog.

Tobin, K., & Capie, W. (1980). *The development and validation of a group test of logical thinking.* Paper presented at the annual meeting of the American Educational Research Association, Boston.

Tobin, K., & Capie, W. (1981). The development and validation of a group test of logical thinking. *Educational and Psychological Measurement, 41, 413-423.*

WAEC. (2005). *Chief Examiners' Reports*. Lagos: Nigeria Animo press Ltd 114-135West African Examinations Council (2005): The West African Senior School Certificate Examinations, May/June (2005) Chief Examiners reports (Nigeria). Lagos 157-196.

WAEC *Chief Examiners reports* (2007): The West African Senior School Certificate Examinations, May/June (Nigeria). Lagos 158-189.

WAEC *Chief Examiners reports* (2009): The West African Senior School Certificate Examinations, May/June (Nigeria). Lagos.

Zadra, E. (2000, April-June). Learning as a gateway to the 21st century. *International Institute for Educational Planning* Newsletter, 18 (2), 14.