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A Description of Formal Reasoning Ability and Its Relationship with Chemistry Learning Outcomes of Grade XI Senior High School Students

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Abstract
This study aims to describe students' formal reasoning ability and its relationship with chemistry learning outcomes among Grade XI students in the Chemistry 1 and Chemistry 3 specialization classes at a public senior high school in Pontianak City during the first semester of the 2024/2025 academic year. The data collection instrument employed was a formal reasoning ability test developed by Burney. The findings revealed that the majority of students' formal reasoning abilities were categorized as low, with most students still at the concrete and transitional stages. Among the five aspects of formal reasoning, the probabilistic aspect was the most mastered (71%) compared to the others, whereas the combinatorial aspect was the lowest (21%). Although most students achieved the Minimum Mastery Criterion (MMC) in their academic performance, no significant relationship was found between formal reasoning ability and chemistry learning outcomes. This is attributed to the dominance of students who remain at the concrete stage (54.29%), which limits their ability to comprehend abstract chemistry concepts. These findings indicate a mismatch between academic achievement and formal reasoning ability, and highlight the importance of implementing systematic and contextual learning strategies to enhance students' formal reasoning in understanding chemistry concepts.

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INTRODUCTION

Chemistry is a branch of science that studies the composition, structure, and properties of matter, as well as the energy changes accompanying these processes (Petrucci et al., 2011). As a discipline grounded in experimentation, chemistry requires reasoning skills and logical thinking to understand natural phenomena, particularly those involving the transformation of substances (Depdiknas, 2003). Consequently, learning chemistry demands high levels of intellectual ability from students to comprehend various abstract concepts (Astutik, 2021).

Difficulties in learning chemistry at the senior high school level are complex problems influenced by limited conceptual understanding, weak mathematical skills, and low learning motivation (Priliyanti et al., 2021). These challenges are further exacerbated by the psychological instability of adolescents, stemming from physical, behavioral, and emotional changes, which often disrupt their learning focus (Husni, 2017). Research by Nadila & Mawarnis (2023) revealed that internal factors such as psychological aspects (82.14%) and emotional aspects (71.43%) were the dominant triggers. This emotional immaturity affects students' ability to think abstractly and logically, especially when dealing with conceptual chemistry material (Laliyo et al., 2017).

According to Piaget's theory of cognitive development, individuals enter the formal operational stage at approximately 11 years of age and above, a stage in which they are expected to be capable of abstract and logical thinking (Marinda, 2020). In chemistry learning, formal reasoning ability is crucial as it encompasses higher-order thinking skills such as hypothetical-deductive reasoning, combinatorial logic, control of variables, as well as reflective and proportional reasoning (Ledoh, 2024; Maulana, 2024).

Data from SMA Negeri 8 Pontianak show that 12.86% of students still obtained low scores in chemistry, while 87.14% achieved mastery. According to Piaget's theory, Grade XI senior high school students aged approximately 15–17 years should have reached the formal operational stage (Azzahra et al., 2023). This fact indicates that some students may still face difficulties in developing their formal reasoning ability, which in turn affects their chemistry learning outcomes.

Previous studies have shown that many senior high school students have not yet reached the formal reasoning stage. Laliyo et al. (2017) reported that the average formal reasoning ability of students was only 10%. At SMA Negeri 9 Pontianak, only 19.44% of students had reached the formal stage, with a positive correlation of 0.514 with chemistry learning outcomes (Juliansyah et al., 2016). Conversely, higher results were reported by Ledoh (2024), who found a significant correlation of 0.909 between formal reasoning and chemistry learning outcomes. Similarly, Rizki et al. (2016) stated that an improvement in formal reasoning positively impacts learning achievement. These findings indicate that the higher the students' formal reasoning ability, the better their learning outcomes.

Most previous studies were conducted during the implementation of the 2013 Curriculum, whereas this study was carried out under the implementation of the Independent Curriculum. The 2013 Curriculum, which emphasizes a scientific approach, has been considered to provide limited opportunities for students to develop creativity and critical thinking skills (Fauzi, 2025; Pertamasari & El-Yunusi, 2024). In contrast, the Independent Curriculum offers greater flexibility in selecting learning models that align with students' interests and characteristics (Fauzan et al., 2023; Hasibuan et al., 2024) This curriculum emphasizes project-based learning, scientific literacy, and flexibility, which support the enhancement of students' critical and reflective thinking skills (Fatmawati & Rusmini, 2023; Williamson, 2023). Ramadhani (2022) demonstrated that this approach can significantly improve students' critical thinking abilities. These abilities share similar characteristics with formal reasoning, particularly in logical, analytical, and systematic thinking when solving chemistry problems. Therefore, through the implementation of this more adaptive curriculum, students' formal reasoning abilities are also expected to improve.

Based on the aforementioned discussion, there remains a gap in the attainment of formal reasoning levels among senior high school students, particularly in understanding abstract and complex chemistry concepts. Meanwhile, the implementation of the Independent Curriculum is expected to provide greater opportunities for students to develop their formal reasoning abilities. Therefore, this study aims to analyze "The Description of Formal Reasoning Ability and Its Relationship with Chemistry Learning Outcomes of Grade XI Senior High School Students."

METHOD

This study is a quantitative research employing a correlational approach with a non-experimental design, aimed at investigating the relationship between formal reasoning ability (X) and students' learning outcomes (Y). Based on the proposed hypothesis, the research model design is as follows:

Figure 1. Research Design

Description:
X: Formal Reasoning Ability
Y: Learning Outcomes

Population and Sample

The population in this study consisted of all Grade XI students specializing in chemistry at SMA Negeri 8 Pontianak in the 2024/2025 academic year. The sample was selected using purposive sampling with criteria representative of the population, comprising 70 students from Grade XI Chemistry Specialization 1 and Chemistry Specialization 3 classes.

Data Collection Techniques

Data were collected through:
1. Test: Students' formal reasoning test (Google Form).
2. Documentation: Chemistry learning outcomes taken from the odd semester report card of 2024.
3. Interview: Unstructured interviews with 6 students and 1 chemistry subject teacher

Research Instrumen

The formal reasoning test employed the *Piagetian Objective Formal Instrument* (POFI) developed by Burney (KPF-T), consisting of 24 objective items. The test results were categorized according to the following criteria:

Table 1. Criteria for Formal Reasoning Test Scores

Score Range	Reasoning Level
17-24	Formal
11-16	Transitional
0-10	Concrete

Students who reached the formal reasoning stage were further analyzed based on specific aspects of formal reasoning as determined by the test items. These aspects and corresponding item numbers are outlined below:

Table 2. Test Items by Formal Reasoning Aspect

Item Number	Aspect of Formal Reasoning
1-3,13-17	Correlational
4-5	Variable Control
6-9,18	Proportional
10-12	Probabilistic
19-24	Combinatorial

Data Analysis Techniques

Data were analyzed using descriptive and inferential statistics.
1. Descriptive Statistics: Calculating the percentage of students who reached the formal reasoning level.

2. Inferential Analysis: Starting from prerequisite tests (normality test using Kolmogorov–Smirnov, homogeneity test using Levene's Test, and linearity test) to hypothesis testing (Pearson Product-Moment Correlation) using SPSS 27

Furthermore, to determine the strength of the relationship between formal reasoning ability (independent variable) and chemistry learning outcomes (dependent variable), an interpretation table was used. The correlation value was determined based on the correlation coefficient (r), with the interpretation of values shown in Table 3:

Table 3. Interpretation of Correlation Coefficients

Correlation Coefficient (r)	Strength of Relationship
0.80 - 1.00	Very Strong
0.60 - 0.79	Strong
0.40 - 0.59	Moderate
0.20 - 0.39	Low
0.00 - 0.19	Very Low

(Sugiyono, 2020: 248)

RESULTS AND DISCUSSION

Description of Formal Reasoning Ability Data

Formal reasoning, as the ability to think logically and abstractly, plays a crucial role in chemistry learning, given that chemistry contains many abstract concepts and requires logical analysis. Based on the results of the formal reasoning test administered to Grade XI students at SMA Negeri 8 Pontianak using Burney's instrument, only 8.57% of students were categorized as having formal reasoning ability, 37.14% were at the transitional stage, while the majority (54.29%) remained at the concrete stage. This indicates that most students still face difficulties in understanding abstract material or concepts, formulating hypotheses, understanding logical relationships, and drawing conclusions based on the available data. The percentage of students by level of formal reasoning ability can be seen in Figure 2 (N = 70).

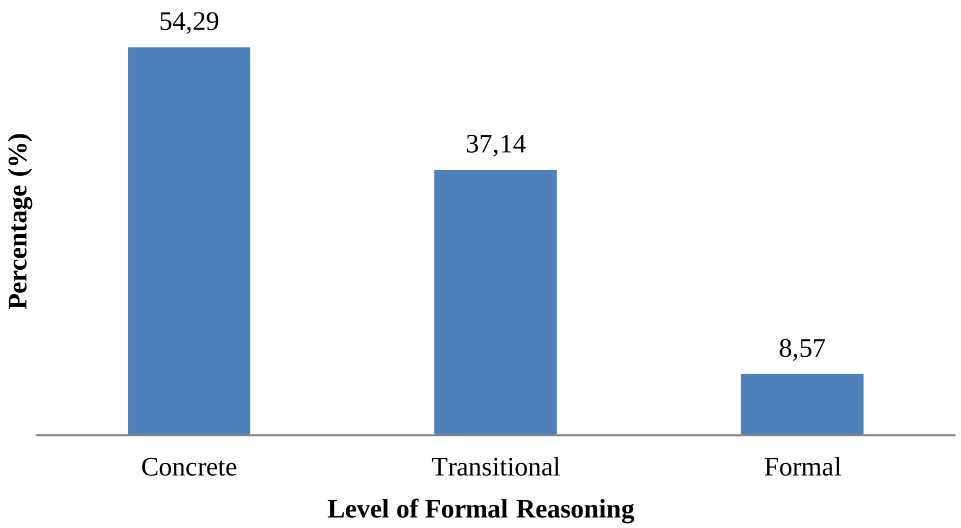

Figure 2. Percentage of students based on the type of formal reasoning ability

When viewed from the aspects of formal reasoning, the probabilistic reasoning aspect showed the highest level of mastery, with 71% of students answering correctly, followed by the proportional aspect (48%), correlational aspect (45%), variable control (37%), and the combinatorial aspect, which had the lowest mastery (21%). The probabilistic aspect reflects students' ability to distinguish between certainty and possibility based on the information available. The high score in this aspect indicates that students are more familiar with the concepts of probability or logical estimation, which may have been acquired from concrete experiences or learning.

In contrast, the low mastery of the combinatorial aspect indicates difficulties in considering all logical alternatives or possible combinations in a given situation (Wahyuni, 2022). This aspect is particularly important in understanding chemistry material because it trains students to think in terms of calculating possibilities, connecting various logical elements, and forming the foundation of abstract reasoning essential for systematically analyzing scientific problems. The low mastery in the combinatorial aspect is supported by interview results from six students, who stated that items 19–24 were quite challenging due to the use of verbal analogy formats that were unfamiliar to them. The strategies used varied, from guessing, comparing the functions of objects, to forming sentences in order to find word relationships. There were no technical difficulties during the test, but the questions were considered highly challenging because they required verbal-logical reasoning rather than mere memorization or calculation.The percentage of students who answered correctly based on the aspects of formal reasoning test items can be seen in Figure 3.

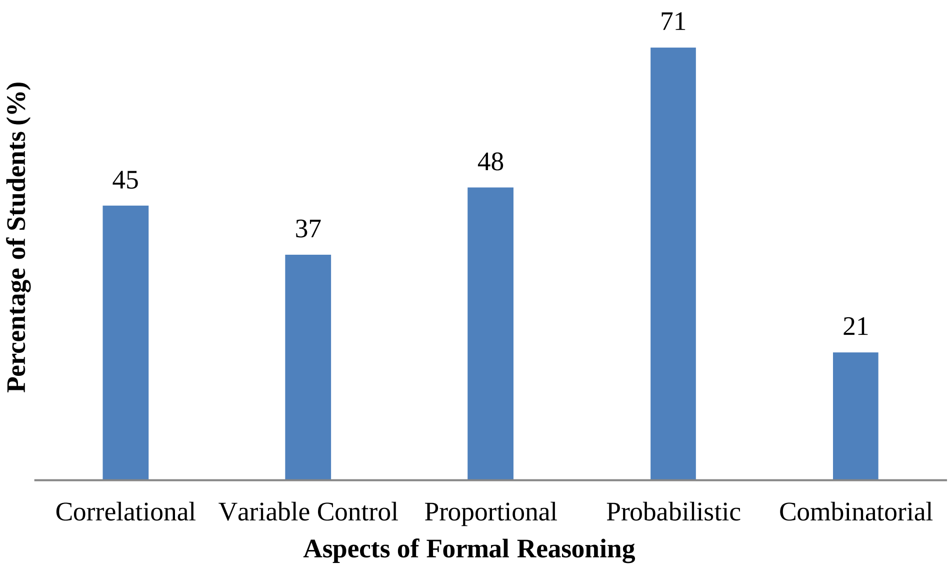

Figure 3. Percentage of students answering correctly based on the aspects of formal reasoning test items

Description of Learning Outcomes Data

The learning outcomes data used in this study were the chemistry subject scores recorded in the report cards of Grade XI students in Chemistry Specialization 1 and Chemistry Specialization 3 at SMA Negeri 8 Pontianak during the first semester of the 2024 academic year. These scores reflect the students' academic achievement after participating in the learning process for one semester. Based on the collected data, the highest score obtained by students was 95, the lowest was 75, and the average learning outcome score was 74.57. Of all the students analyzed, 87.14% met the mastery criterion, while 12.86% did not achieve mastery (consisting of 6 students from Chemistry Specialization 1 and 3 students from Chemistry Specialization 3), as presented in Table 4.

Table 4. Percentage of Students' Mastery Level in Learning Outcomes

Class	Number of Students	Passed ≥ 80	Not Passed ≤ 80
Chemistry Specialization 1	33	27	6
Chemistry Specialization 3	37	34	3
Total		61	9
Percentage		87,14%	12,86%

Most students achieved academic scores that met the Minimum Mastery Criterion (MMC = 80). This is because students' learning outcomes are influenced by various interrelated factors, both internal and external. Internal factors such as logical and abstract thinking ability (formal reasoning), emotional intelligence, and learning motivation play a crucial role in understanding complex academic concepts, such as those in chemistry (Jeihn et al., 2024; Nirtha et al., 2024). In addition, external factors such as the learning environment, academic support, and quality of instruction also affect students' academic achievement (Nirtha et al., 2024; Wardiyah, 2022). Jean Piaget's theory of cognitive development suggests that children's thinking develops gradually in stages according to age and cognitive maturity, and is influenced by adaptation processes such as assimilation, accommodation, and equilibration (Putra, 2022). Heredity, interests, talents, and freedom of thought also contribute to the speed and effectiveness of children's learning (Susanto, 2011; Wardiyah, 2022). Teachers also stated that some students with a strong foundation are able to understand the material because they engage in independent learning outside of school, enabling them to grasp abstract concepts.

Thus, although many students have achieved the MMC academically, this does not necessarily reflect their actual formal reasoning ability. Therefore, in assessing learning achievement, it is important to also consider factors influencing cognitive aspects such as logical and abstract thinking ability, emotional readiness, and comprehensive learning environment support.

Relationship Between Formal Reasoning Ability and Learning Outcomes

To examine the relationship between formal reasoning ability and the learning outcomes of Grade XI students in Chemistry Specialization 1 and Chemistry Specialization 3 at SMA Negeri 8 Pontianak, a correlation test was conducted using the Statistical Package for the Social Sciences (SPSS) version 27 for Windows. Prior to performing the correlation test, prerequisite tests were carried out to ensure that the assumptions of parametric statistics were met. The normality test results using the Kolmogorov–Smirnov method indicated that the data were normally distributed, with a significance value of 0.200 (> 0.05). Therefore, the data met the normality assumption, allowing the correlation analysis to proceed. The results of the normality test analysis for formal reasoning ability and students' learning outcomes are presented in Table 4.

The homogeneity test using Levene's Test was employed to determine whether the variance of data among groups in this study was homogeneous. The results indicated that the students' learning outcomes data met the homogeneity assumption, with a significance value of 0.400, which is greater than the significance threshold of 0.05. This finding suggests that the variance among the data groups did not differ significantly, thus confirming that the data were homogeneous. This condition allows for the application of parametric statistical analysis in the subsequent stage.

Table 4. Results of Normality Test Analysis for Formal Reasoning Ability and Students' Learning Outcomes

One-Sample Kolmogorov-Smirnov Test

			Unstandardized Residual
N			70
Normal Parameters[a,b]	Mean		.0000000
	Std. Deviation		4.80552019
Most Extreme Differences	Absolute		.086
	Positive		.046
	Negative		-.086
Test Statistic			.086
Asymp. Sig. (2-tailed)[c]			.200[d]
Monte Carlo Sig. (2-tailed)[e]	Sig.		.219
	99% Confidence Interval	Lower Bound	.209
		Upper Bound	.230

The complete results of the homogeneity test analysis on students' learning outcomes are presented in Table 5.

Table 5. Results of the Homogeneity Test Analysis on Students' Learning Outcomes

Test of Homogeneity of Variance

		Levene Statistic	df1	df2	Sig.
Hasil Belajar Siswa	Based on Mean	.718	1	68	.400
	Based on Median	.691	1	68	.409
	Based on Median and with adjusted df	.691	1	67.644	.409
	Based on trimmed mean	.724	1	68	.398

After the data were declared normal and homogeneous, a linearity test was conducted to determine the form of the relationship between formal reasoning ability and chemistry learning outcomes. The test results showed a significance value for deviation from linearity of 0.392. This indicates that the relationship between the variables is linear, allowing for correlation analysis to be conducted. A summary of the linearity test results is presented in Table 6.

Table 6. Results of the linearity test analysis of formal reasoning ability and students' learning outcomes

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Hasil Belajar Siswa * Kemampuan Penalaran Formal	Between Groups	(Combined)	400.004	16	25.000	1.087	.390
		Linearity	25.724	1	25.724	1.118	.295
		Deviation from Linearity	374.280	15	24.952	1.085	.392
	Within Groups		1219.139	53	23.003		
	Total		1619.143	69			

The Pearson Product-Moment correlation test was then conducted to determine the relationship between formal reasoning ability and chemistry learning outcomes. The analysis results showed a correlation coefficient of $r = 0.126$ with a significance level of $p = 0.298$.

This value indicates that the relationship between the variables is very weak and statistically not significant. Therefore, it can be concluded that there is no strong relationship between formal reasoning ability and students' chemistry learning outcomes. The results of the Pearson Product-Moment correlation analysis are presented in Table 7.

Table 7. Results of Pearson Product-Moment Correlation Analysis between Formal Reasoning Ability and Students' Chemistry Learning Outcomes

Correlations

		Kemampuan Penalaran Formal	Hasil Belajar Siswa
Kemampuan Penalaran Formal	Pearson Correlation	1	.126
	Sig. (2-tailed)		.298
	N	70	70
Hasil Belajar Siswa	Pearson Correlation	.126	1
	Sig. (2-tailed)	.298	
	N	70	70

These findings differ from several previous studies that reported a significant relationship between formal reasoning ability and learning achievement, such as those by Laliyo et al. (2017), Juliansyah et al. (2016), and Ledoh (2024), which demonstrated a strong correlation between the two variables. The absence of a significant relationship in the present study is presumed to be due to the majority of students still being at the concrete stage (54.29%), thereby limiting their ability to comprehend abstract chemical concepts. In contrast to earlier studies reporting a moderate correlation, the majority of their samples were in the transitional stage toward the formal stage, thus being able to apply hypothetical-deductive reasoning to a limited extent. This is consistent with Piaget's theory, which states that students at the transitional or formal operational stage tend to be more capable of logically understanding abstract concepts in science learning (Piaget, 1972).

Conversely, the present findings align with those of Mirna (2015), who also found no significant relationship between the two variables. Furthermore, the learning achievement data used in this study were derived from odd semester report card grades, which reflect general academic performance and do not solely represent conceptual reasoning ability. High report card scores may be influenced by various non-cognitive factors, such as discipline, class participation, or teacher assistance during the learning process. Therefore, the low formal reasoning ability that does not align with relatively high report card scores resulted in the relationship between the two variables being statistically insignificant in this study.

Accordingly, the results of this study indicate that, in general, students' formal reasoning levels remain low, even though the majority have achieved academic mastery. This finding affirms that academic achievement does not necessarily reflect the ability to engage in formal reasoning. Therefore, the development of formal reasoning cannot rely solely on classroom learning but requires the implementation of active learning strategies, the habituation of logical thinking, as well as support from the home and surrounding environment to holistically facilitate students' learning processes.

CONCLUSION

Based on the findings and discussion, it can be concluded that the formal reasoning ability of Grade XI senior high school students is categorized as low. The majority of students (54.29%) are at the concrete thinking stage. Furthermore, the relationship between formal reasoning ability and learning outcomes is very weak ($r = 0.126$; $p = 0.298$). Therefore, teachers are required to implement strategies that can enhance students' reasoning abilities, such as the inquiry approach (Yulianti & Zhafirah, 2020), cooperative learning (Rahmawati, 2017), discovery learning (Togi & Sagala, 2017), problem-based learning (Fitriyani & Duran Corebima, 2015), or project-based learning models (Ridwan et al., 2024).

RECOMMENDATIONS

For future researchers, it is recommended to conduct a more in-depth investigation into potential mediating factors that may influence the relationship between formal reasoning and learning outcomes, such as learning motivation, learning styles, and the assessment methods employed. Further studies may also be extended to different grade levels or types of schools to obtain a more comprehensive and representative understanding.

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