



## Profiles of Students' Logical-Mathematical Reasoning in Statistical Physics Learning: Differentiated Learning and Computer Simulation Perspectives

Dens E. S. I. Asbanu, Yusi Riksa Yustiana , Parlindungan Sinaga, Febrian Virijai

Universitas Pendidikan Indonesia

Jl. Dr. Setiabudhi No. 229, Kota Bandung, Jawa Barat, Indonesia

[|yusiriksa@upi.edu](mailto:yusiriksa@upi.edu)  | DOI: <https://doi.org/10.37729/radiasi.v19i1.6022> |

### Abstract

*This study aims to analyze the logical-mathematical thinking ability of prospective physics teacher students as a basis for designing learning strategies based on differentiated learning and computer simulation. The survey method involved 37 physics education study program students from one of the universities on the island of Timor. Data was collected through a logical thinking ability test covering five main types of reasoning: proportional, variable control, probability, correlation, and combinatorial. The analysis results showed that most students were at the level of transitional logical thinking (70 percent), while only 11 percent reached the formal level. The chi-squared test showed a significant relationship between the semester level and students' logical thinking ability. These results show the need for learning that supports the transition from concrete and transitional thinking to formal. Implementing computer simulation in statistical physics learning is recommended to improve students' logical-mathematical thinking skills, support the understanding of abstract concepts, and facilitate the success of complex physics learning.*

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## 1. Introduction

In the modern era, education emphasizes the importance of a pedagogical approach that respects the diversity and uniqueness of individuals in the learning process. One approach that is relevant to this need is differentiated learning [1]. This approach is rooted in a humanistic philosophy. Rogers believes that teachers, as learning facilitators, must build empathy and trust and prioritize students' learning needs [2]. This philosophy believes that each individual has a unique potential that can develop through personalized learning. Differentiated learning aims to accommodate the diversity of individual learning needs. In this context, learning strategies must be designed considering each individual's learning style, cognitive style, prior knowledge, and learning experience [3][4]. This approach is particularly relevant in higher education, especially for prospective physics teacher education programs, as it can prepare students with the critical and adaptive thinking skills needed in complex physics learning.

One of the essential elements in the learning strategy in higher education is the student's prior knowledge. Initial knowledge is the foundation for understanding and integrating new information. In this case, the ability to think logically and mathematically is an essential skill that prospective physics teacher students must possess [5]. These skills include formal, concrete, and transitional thinking, the basis for designing effective learning strategies.

The ability to think logically in a mathematical context includes deductive and inductive reasoning, understanding and proving theorems, and systematic problem-solving [6][7]. This ability involves pattern recognition, generalization, information analysis, and synthesis [8][9]. Thus, the ability to think logically becomes an essential component of physics learning, especially in understanding abstract concepts and complex mathematical equations. However, various studies have shown that prospective physics teacher students often struggle to understand abstract concepts in statistical physics, such as Boltzmann distribution, partition functions, and entropy, which require a high level of logical and mathematical reasoning [10][11], [12]. These challenges include difficulties in interpreting mathematical relationships, limited understanding of probability principles, and weaknesses in deductive and inductive reasoning. Unfortunately, there is still a lack of research that specifically maps the profile of students' logical-mathematical reasoning abilities in the context of statistical physics learning. Therefore, this study aims to analyze the types and levels of logical-mathematical reasoning among prospective physics teacher students at the SoE Institute of Education. The findings are expected to serve as a foundation for designing differentiated learning strategies in statistical physics that are aligned with students' individual needs and to address the research gap in this area.

Statistical physics has the characteristics of abstract materials and involves complex mathematics, so one of the critical factors that must be considered in the design of differentiation learning-based learning is the ability of students to think logically and mathematically. Therefore, this study aims to analyze the type and level of mathematical and logical reasoning of prospective physics teacher students at the SoE Institute of Education. This analysis is expected to be the basis for understanding the diversity of mathematical and logical thinking skills, which is further helpful in developing statistical physics learning strategy designs that suit the individual needs of learners.

## 2. Methods

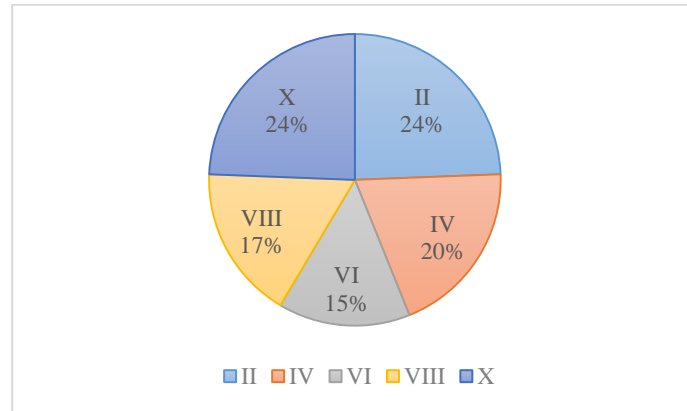
This study employed a quantitative approach using a descriptive survey method [13]. The purpose of this method is to describe the profiles of students' logical-mathematical reasoning in statistical physics learning. The research sample consisted of students from the physics education study program at a private university on the island of Timor. The inclusion criteria for participants were: currently enrolled in the program, actively attending lectures during the even semester of 2024, and not on academic leave or having dropout status. Based on these criteria, 42 students were identified as eligible research participants. The sample of participating students was determined using a simple random sampling technique. The minimum number of samples was calculated using the Slovin formula with a significance level of 95% ( $\alpha = 5\%$ ), so 37 participants were obtained. Qualitative data were collected using the cross-sectional survey method, while quantitative data were obtained through tests.

Test instruments to measure students' logical thinking skills are distributed offline. The logical thinking ability test instrument uses a standard test consisting of 10 questions. Each question has an alternative answer accompanied by a reason. Test takers get a score of 1 if they choose the correct answer alternative and give the right reason, with a maximum total score of 10. This instrument is designed to measure five main types of reasoning, namely proportional reasoning (2 questions), variable control (2 questions), probability reasoning (2 questions), correlational reasoning (2 questions), and combinatorial reasoning (2 questions).

The data analysis technique uses Microsoft Excel to describe data through tables and conventions. The data analysis used a chi-square test to determine the relationship between mathematical, logical ability, and semester rate because the number of samples was small and not normally distributed. The chi-square test used SPSS 21.

### 3. Results and Discussion

The measurement of logical-mathematical reasoning was conducted based on five indicators: proportional reasoning (two items), variable control (two items), probability reasoning (two items), correlational reasoning (two items), and combinatorial reasoning (two items). The survey instrument was administered to 37 participants, specifically students enrolled in the Physics education study program at the SoE Institute of Education. The demographic characteristics of the 37 participants are presented in Figure 1.



**Figure 1.** Participant Demographics

The results of the mathematical, logical thinking ability test on each indicator are shown in Table 1.

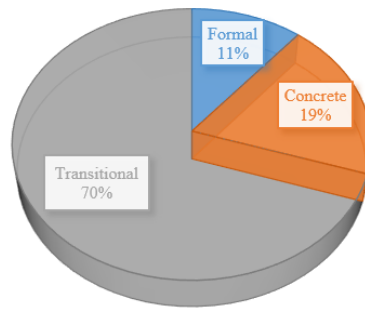
**Table 1.** Score per Indicator of Mathematical Logical Thinking

No	Indicator	Score	Mean	Std. deviasi
1	Proportional reasoning	21	0.32	0.47
2	Variable control	9	0.12	0.33
3	Probability reasoning	10	0.14	0.34
4	Correlational reasoning	20	0.27	0.45
5	Combinational reasoning	21	0.28	0.45

The data analysis in Table 1 shows the lowest score in the type of logical thinking ability to control variables with the maximum score and the highest score in proportional and combinatorial reasoning. The ability to think logically is categorized into 3, namely concrete, transitional, and formal skills. The classification of physics is based on the logical thinking test score (Table 2).

**Table 2.** Number of Participants Based on Logical Thinking Ability

Score range	Categories of logical thinking skills	
0-1	Concrete	7
2-3	Transisional	26
4-10	Formal	4



**Figure 2.** Percentage of Participants Based on Logical Thinking Ability

Based on Figure 2 and Table 2, it was found that the logical thinking ability of the participants was the highest in the transitional logical thinking ability, which was 26 students out of 37 students or 70% of the total respondents, and the lowest in formal thinking ability, which was 4 people out of 37 respondents or 11% of the total respondents. While thinking concretely, there were 7 out of 37 respondents, or 19% of the total respondents.

**Table 3.** Mathematical Logical Thinking Ability Score by Semester

Semester	Logical thinking skills			Total
	Concrete	Transitional	Formal	
II	4	16	0	20
IV	2	8	6	16
VI	0	12	0	12
VIII	0	12	2	14
X	8	4	0	12
Total	14	52	8	74

Based on Table 3 a statistical test was carried out to evaluate the significant relationship between the semester level of students and the ability to think logically using *chi-square*. The participant data used was 37 students at five-semester levels (II, IV, VI, VIII, X) obtained chi-square calculate =  $\chi^2_{\text{count}} = 59.95 > \chi^2_{\text{count}} (df = 8, \alpha = 0.05)$ . Therefore, it was concluded that there was a significant relationship between the semester level and the student's logical thinking ability. Based on descriptive analysis of the logical thinking ability test and the chi-square test, the study's findings showed a significant relationship between the semester level and students' logical thinking ability. However, the logical thinking ability of prospective physics teacher students is still at a transitional and concrete level, even in semesters 6 to 10.

According to Jean Piaget's theory of cognitive development, students who are still at the transitional and concrete level have not fully developed the abstract and logical thinking skills needed in advanced physics studies. In the operational concrete stage, individuals begin to think logically about real objects and events but still struggle with abstract concepts. The formal operational stage, usually achieved after age 11, is characterized by the ability to think logically about abstract ideas and hypotheses. Mathematical and logical thinking skills are important because they foster critical thinking and complex problem-solving skills in various scientific fields, including physics [14][15]. The development of mathematical logical thinking skills can be done through problem-based learning that increases students' active involvement to train their analytical thinking skills that can be transferred in solving physics problems [16]. This is because mathematics is the language of science used to communicate concepts, laws, and theories of physics [17].

Through his theory of the Zones of Proximal Development (ZPD), Lev Vygotsky emphasized the importance of social interaction in cognitive development. ZPD is the distance between what a student can do with help and what they can do on their own [18][19]. In this context, appropriate educational interventions, such as the use of computer simulations, can serve as tools to help students move from concrete to formal thinking. Computer simulations can play an important role in supporting students to overcome difficulties in understanding abstract concepts [20]. Several previous studies have shown that computer simulations in science learning can improve understanding of scientific concepts by allowing students to conduct virtual experiments that cannot be done in a real laboratory [21][22]. This shows the potential of computer simulations to help students understand more abstract physics concepts. The use of computer simulations in physics learning helps students understand abstract concepts such as Newton's laws and parabolic motion better than traditional learning methods [23].

Computer simulations in physics learning can have a significant positive impact. Computer simulations allow for the visualization of elusive physics concepts, such as electric and magnetic fields, light interference, and relativity [24][25]. Simulation-based learning can start with concrete concepts and gradually switch to abstract concepts through inquiry activities can develop students' logical reasoning [26] [27][28] [29]. With this strategy, students are expected to progress from transitional and concrete thinking to formal thinking necessary for academic and professional success in physics.

## 4. Conclusion

The results showed that students' mathematical logical thinking skills were highest in the type of reasoning with variable control, with a logical thinking profile at the concrete and transitional levels. A significant relationship exists between mathematical logical thinking ability and student semester level. Efforts to improve students' thinking skills from the concrete and transitional level to the formal level can be made through differentiated learning that is integrated with computer simulations.

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