JPPIPA 11(12) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Analytical Thinking Abilities in Physics Education Students: A Rasch-Based Diagnostic Study

Amsor[1*], M Reza Dwi Saputra[1], Nurdini[1], Filzah Nabila Asri[1], Siti Almaidah[1]

[1]Physics Education Study Program, Faculty of Mathematics and Science Education, Universitas Pendidikan Indonesia, Bandung, Indonesia.

Received: October 12, 2025
Revised: November 23, 2025
Accepted: December 29, 2025
Published: December 31, 2025

Corresponding Author:
Amsor
amsor.fisika@upi.edu

DOI: 10.29303/jppipa.v11i12.13444

Abstract: Analytical thinking is essential for physics education students, yet comprehensive assessment remains challenging. This study investigates the distribution and characteristics of analytical thinking abilities using Rasch model analysis, examining gender differences and performance patterns. A cross-sectional study was conducted with 35 physics education students (20 females, 15 males) using a 20-item multiple-choice assessment covering four domains: identifying problems, recognizing relational patterns, identifying reasoning errors, and summarizing main ideas. Data were analyzed using Winsteps software to examine person abilities and group comparisons. Results revealed highly variable analytical thinking abilities (range = 8.84 logits, M = -0.15, SD = 1.79). Males outperformed females by 0.46 logits (males: M = 0.15; females: M = -0.31), though not statistically significant ($p > 0.05$). Three performance levels emerged: high achievers (25.7%, n = 9), average achievers (48.6%, n = 17), and low achievers (25.7%, n = 9). The findings reveal significant heterogeneity in analytical thinking abilities with observable gender-based differences. Results suggest the need for differentiated instructional approaches tailored to varying ability levels and targeted interventions to support struggling students. This study demonstrates the utility of Rasch analysis in identifying areas for instructional improvement and optimizing analytical thinking development in physics education contexts.

Keywords: Analytical thinking; Physics education; Rasch model; Student ability; Gender difference

Introduction

Analytical thinking represents a cornerstone cognitive ability in physics education, encompassing the capacity to systematically decompose complex problems, identify underlying patterns, and construct logical solutions (Brookhart 2010; Çoksan and Yilmaz 2024; Lombardi 2023). According to Bloom's revised taxonomy, analytical thinking operates at higher cognitive levels—specifically analyzing, evaluating, and creating—which are essential for deep conceptual understanding and knowledge application (Maqruf et al. 2024). In the context of physics education, analytical thinking enables students to navigate abstract concepts, apply mathematical reasoning, and develop coherent understanding of physical phenomena (Hong 2022). This cognitive skill is particularly crucial because physics requires students to move beyond surface-level memorization toward the integration of mathematical formalism, conceptual reasoning, and empirical observation.

Beyond academic settings, analytical thinking is essential for addressing real-world problems, succeeding in professional environments, and maintaining global competitiveness. The OECD's framework for 21st-century competencies emphasizes critical thinking and problem-solving as core skills necessary for navigating complex, rapidly changing societies (Hajkowicz et al. 2023). In the 21st century, graduates are increasingly expected to make informed decisions, adapt to complex situations, and solve problems systematically—skills that are foundational for success in diverse and evolving workplaces (Anthonysamy et al. 2024; Mohareb and Al Khraisha 2025). Physics education students, in particular, must possess strong analytical thinking skills not only to

How to Cite:
Amsor, A., Saputra, M. R. D., Nurdini, N., Asri, F. N., & Almaidah, S. (2025). Analytical Thinking Abilities in Physics Education Students: A Rasch-Based Diagnostic Study. *Jurnal Penelitian Pendidikan IPA*, *11*(12), 640-651. https://doi.org/10.29303/jppipa.v11i12.13444

understand physics concepts but also to guide future learners in mastering these skills. As prospective educators, their analytical competencies will directly influence the quality of instruction and cognitive development of the next generation of students.

Despite the recognized importance of analytical thinking, significant gaps remain in understanding how these abilities are distributed among physics education students and what instructional strategies can effectively address performance disparities. Although analytical thinking is emphasized in various national and international educational frameworks, few studies have systematically mapped the actual thinking profiles and performance patterns of physics education students using validated instruments. Existing research often focuses on general cognitive development or traditional academic achievement, lacking in-depth psychometric diagnosis of higher-order skills such as analytical thinking (Dewi et al. 2024; Surin and Damrongpanit 2024). This represents a critical knowledge gap, as evidence-based instructional design requires precise understanding of student ability distributions and learning needs.

Moreover, while validated instruments for analytical thinking assessment exist, they are rarely employed to comprehensively evaluate student ability distributions in specific educational domains, such as physics education. The application of advanced psychometric methods, particularly in non-Western educational contexts, remains limited despite their potential to reveal nuanced performance patterns that traditional assessments overlook.

The development of analytical thinking skills has become increasingly critical in modern science education, particularly as curricula emphasize scientific reasoning, conceptual understanding, and problem-solving over rote memorization (Karla et al. 2022; Nieto-Jalil, Lozano-Aponte, and Rojas 2024). Constructivist learning theory posits that meaningful learning occurs when students actively construct knowledge through analysis, synthesis, and application rather than passive reception (Vygotsky, 1978; Piaget, 1952). This theoretical foundation underscores the necessity of developing analytical thinking as a mechanism for deep learning in physics. However, traditional assessment methods often fall short in capturing the multidimensional nature of analytical thinking, leading to incomplete profiles of student abilities and learning needs (Demir 2022; Hidayat et al. 2024; Surin and Damrongpanit 2024). Without accurate ability profiling, educators cannot effectively differentiate instruction or provide targeted support to students at varying performance levels.

Recent pedagogical innovations such as 3D printing, STEAM-based simulators, digital learning, and collaborative instructional modules have shown potential in fostering analytical thinking (Greenholts and Verner 2020; Levin and Verner 2020; Setiaji et al. 2023). These approaches emphasize student-centered learning, cognitive engagement, and higher-order reasoning, aligning well with the demands of analytical thinking development. However, the effectiveness of these interventions depends on baseline understanding of student capabilities and identification of specific areas requiring improvement.

Rasch measurement theory offers a sophisticated psychometric framework for examining cognitive abilities, grounded in the principle of probabilistic test theory and the assumption that person ability and item difficulty can be estimated independently (Rasch, 1960; Bond and Fox, 2015). It provides interval-level measurement, controls for measurement error, and enables detailed analysis of both person abilities and item characteristics on a shared logit scale (Altıntaş and Kutlu 2020; Wiyarsi et al. 2019). Unlike classical test theory, which relies on sample-dependent statistics, Rasch modeling supports the identification of learning gaps, misfitting response patterns, and subgroup performance differences with statistical rigor and sample-independent parameter estimation. This theoretical advantage makes Rasch analysis particularly suitable for diagnostic educational assessment and individualized learning support.

Although Rasch analysis has gained recognition in educational research, limited studies have applied this method to analyze analytical thinking abilities within physics education—especially in Southeast Asian or Indonesian contexts. This geographical gap is significant because educational systems, cultural learning orientations, and curricular emphases differ substantially across regions, potentially influencing how analytical thinking manifests among students. In addition, gender-based performance differences in analytical thinking remain underexplored, despite recurring disparities in STEM achievement and participation (Kocaman 2023; Tosyali and Aktas 2021). Understanding whether and how gender influences analytical thinking performance is essential for developing equitable educational interventions.

Given these considerations, this research is conducted for several critical reasons. First, it addresses the methodological gap by applying Rasch measurement—a robust psychometric approach—to assess analytical thinking in physics education, providing more precise ability estimates than traditional scoring methods. Second, it responds to the contextual gap by examining analytical thinking patterns within the Indonesian higher education system, where physics teacher preparation programs are rapidly expanding yet empirical evidence on student competencies remains scarce. Third, it explores gender differences to inform equity-focused instructional strategies that ensure all students, regardless of gender, have equal opportunities to develop analytical thinking skills. Fourth, the findings will serve as an empirical foundation for designing differentiated instruction and targeted interventions tailored to diverse student ability levels.

This study serves as a preliminary investigation aimed at mapping the analytical thinking abilities of physics education students at Universitas Pendidikan Indonesia. The findings are expected to inform the design of more targeted instructional interventions to enhance students' analytical thinking skills in future educational programs. Specifically, we investigate: (1) the distribution and characteristics of analytical thinking abilities, (2) gender differences in performance patterns, and (3) student performance profiles across different analytical thinking domains. By establishing a detailed ability profile of physics education students, this research contributes both to the theoretical understanding of analytical thinking development and to practical efforts to optimize physics teacher education.

Method

Time and Place of The Research

This research was conducted during the 2023/2024 academic year at Universitas Pendidikan Indonesia. The study involved undergraduate students enrolled in the physics education program and was carried out following institutional ethics approval.

Research Design

This study employed a cross-sectional survey design (see FIGURE 1) to examine analytical thinking abilities among physics education students using Rasch measurement principles.

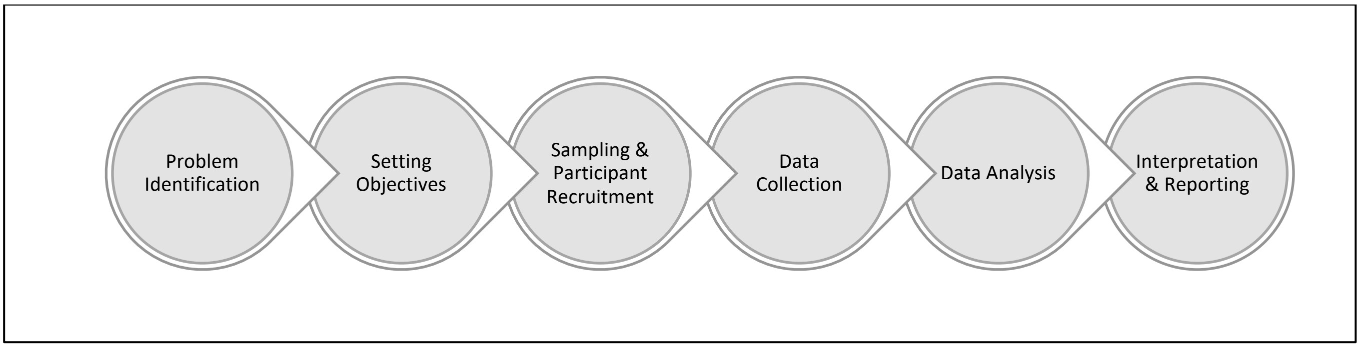


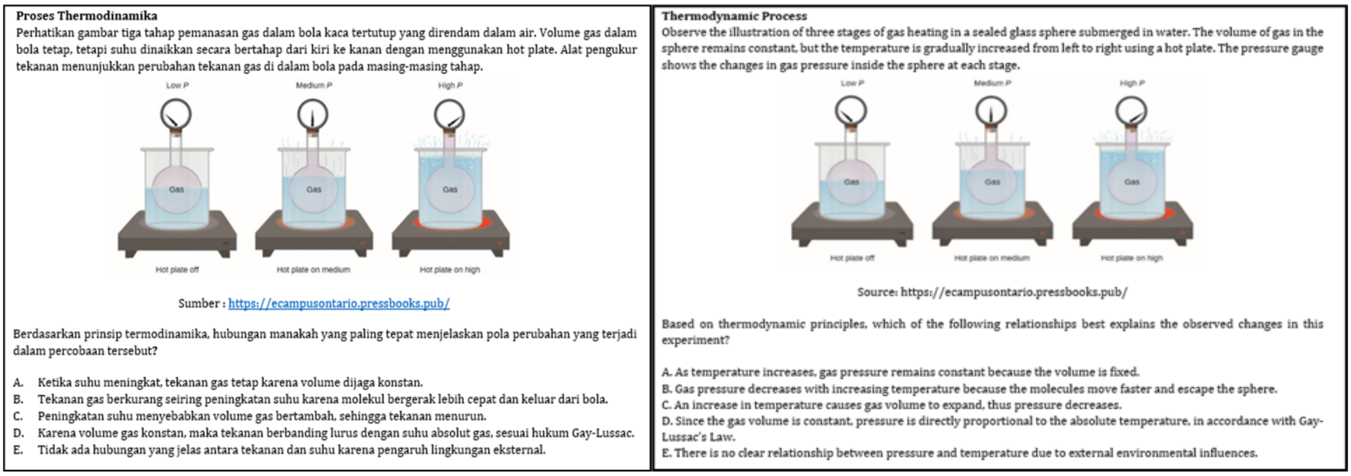
Figure 1. Sequential steps of the cross-sectional survey research design

The population consisted of all undergraduate students enrolled in the physics education program at the university. A total of 35 students (20 females and 15 males) from second to fourth year cohorts participated in this study, with ages ranging from 18 to 22 years (M = 19.4, SD = 1.2). The sample was selected using convenience sampling, a non-probability technique appropriate for exploratory studies where participants are readily accessible (Creswell and Creswell 2018). The sample size met the recommended minimum threshold of 30 participants required for stable parameter estimation in Rasch analysis with dichotomous data (Wright & Stone, 1979). The research variable examined was students' analytical thinking ability, operationalized through performance on a standardized multiple-choice test. Data were collected through a single administration of the analytical thinking assessment instrument. The instrument comprised 20 multiple-choice items covering four analytical thinking domains: (1) identifying problems, (2) recognizing and precisely identifying relational patterns, (3) identifying and evaluating reasoning errors, and (4) summarizing main ideas. The framework was adapted from the National Center for the Improvement of Educational Assessment (NCIEA, 2024) and indicators developed by Fitriani & Fadly (2022). Items were categorized by representational format verbal, visual, and mathematical, to reflect the cognitive diversity required in physics education (see Table 1 and Figure 2).

Table 1. Distribution of Analytical Thinking Test Items Based on Skill Indicators and Representation Categories

Analytical Thinking Skill Indicator	Representation Category	Item Number
Identifying problems	Verbal	1
	Visual	2,3,4
	Mathematical	5,6
Finding and precisely identifying relational patterns	Verbal	7
	Visual	8,9,10,11, 13
	Mathematical	12, 13
Identifying and evaluating reasoning errors	Verbal	14,15
	Visual	16
	Mathematical	17
Summarizing main ideas	Verbal	18
	Visual	19
	Mathematical	20

The instrument had been previously developed and content-validated by three physics education specialists, ensuring its appropriateness for measuring analytical thinking in the target population.


Proses Thermodinamika

Perhatikan gambar tiga tahap pemanasan gas dalam bola kaca tertutup yang direndam dalam air. Volume gas dalam bola tetap, tetapi suhu dinaikkan secara bertahap dari kiri ke kanan dengan menggunakan hot plate. Alat pengukur tekanan menunjukkan perubahan tekanan gas di dalam bola pada masing-masing tahap.

Sumber : https://ecampusontario.pressbooks.pub/

Berdasarkan prinsip termodinamika, hubungan manakah yang paling tepat menjelaskan pola perubahan yang terjadi dalam percobaan tersebut?

A. Ketika suhu meningkat, tekanan gas tetap karena volume dijaga konstan.
B. Tekanan gas berkurang seiring peningkatan suhu karena molekul bergerak lebih cepat dan keluar dari bola.
C. Peningkatan suhu menyebabkan volume gas bertambah, sehingga tekanan menurun.
D. Karena volume gas konstan, maka tekanan berbanding lurus dengan suhu absolut gas, sesuai hukum Gay-Lussac.
E. Tidak ada hubungan yang jelas antara tekanan dan suhu karena pengaruh lingkungan eksternal.

Thermodynamic Process

Observe the illustration of three stages of gas heating in a sealed glass sphere submerged in water. The volume of gas in the sphere remains constant, but the temperature is gradually increased from left to right using a hot plate. The pressure gauge shows the changes in gas pressure inside the sphere at each stage.

Source: https://ecampusontario.pressbooks.pub/

Based on thermodynamic principles, which of the following relationships best explains the observed changes in this experiment?

A. As temperature increases, gas pressure remains constant because the volume is fixed.
B. Gas pressure decreases with increasing temperature because the molecules move faster and escape the sphere.
C. An increase in temperature causes gas volume to expand, thus pressure decreases.
D. Since the gas volume is constant, pressure is directly proportional to the absolute temperature, in accordance with Gay-Lussac's Law.
E. There is no clear relationship between pressure and temperature due to external environmental influences.

Figure 2. Example of an analytical thinking test item in indonesian and english versions

Rasch analysis was conducted using Winsteps software (Linacre, 2023) to estimate person ability measures, examine score distributions, and identify patterns of student performance.

Research Data Analysis

Data analysis was conducted exclusively using Rasch measurement theory to examine students' analytical thinking abilities. Person ability measures were estimated on a logit scale, providing interval-level measurement that allows for meaningful comparisons. The analysis focused on several key aspects: (1) person reliability indices to assess the consistency of the measurement, (2) ability spread to understand the range and distribution of student performance, and (3) gender-based comparisons to identify potential differences between male and female students. Model fit was evaluated using INFIT and OUTFIT mean square statistics, with acceptable values ranging from 0.5 to 1.5, indicating that item responses were consistent with the Rasch model expectations. Statistical comparisons between groups were tested at a significance level of $p < 0.05$, and practical significance was assessed using Cohen's d effect size, where values of 0.2, 0.5, and 0.8 represent small, medium, and large effects, respectively. No item-level analysis, revision, or recalibration was conducted, as the study's purpose was not instrument refinement but rather to explore and describe the analytical thinking ability levels of students and to identify implications for instructional planning and targeted student support interventions.

Result and Discussion

Model Fit and Measurement Quality

Rasch analysis revealed that the analytical thinking instrument yielded strong measurement properties when applied to responses from 35 physics education students. Person reliability reached 0.82, this reliability value is comparable to those reported in similar Rasch-based studies of cognitive assessment in STEM education, where reliability indices typically range from 0.75 to 0.85 (Adawiyah et al. 2020; Altıntaş and Kutlu 2020; Wiyarsi et al. 2019) with a separation index of 2.12 shown in TABLE 2 and FIGURE 3, indicating that the instrument could consistently distinguish students across approximately three levels of ability. Cronbach's alpha was also high (0.87) shown in FIGURE 3, demonstrating internal consistency. Such findings highlight the instrument's suitability for diagnostic and instructional purposes in physics education contexts, aligning with prior research emphasizing the need for valid and reliable tools in assessing complex cognitive skills in STEM domains (Mohareb and Al Khraisha 2025).

Table 2. Summary Statistics for Student Abilities

Statistic	Value
Mean Measure	-0.15 logits
Standard Deviation	1.79 logits
Minimum	-4.43 logits
Maximum	4.41 logits
Range	8.84 logits
Person Reliability	0.82
Cronbach's Alpha	0.87

The targeting analysis showed that the mean item difficulty was 0.00 logits (by default), while the mean student ability was -0.15 logits. This indicates a slight mismatch, where test items were marginally more difficult than the average student's ability (Bond & Fox, 2015; Linacre, 2023). Although minor, this gap suggests that refining the instrument particularly by including easier items could better accommodate the lower-performing cohort and enhance measurement precision.

The output result on Winstep regarding the summary of measured persons can be seen in Figure 3.

```
    SUMMARY OF 35 MEASURED (EXTREME AND NON-EXTREME) Person
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE      COUNT     MEASURE   S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN       9.3       20.0       -.15     .67                                |
|  SEM        .9         .0        .31     .06                                |
| P.SD       5.2         .0       1.79     .37                                |
| S.SD       5.3         .0       1.81     .38                                |
| MAX.      20.0       20.0       4.41    1.83                                |
| MIN.        .0       20.0      -4.43     .48                                |
|-----------------------------------------------------------------------------|
| REAL RMSE    .78 TRUE SD    1.61  SEPARATION  2.07  Person RELIABILITY  .81 |
|MODEL RMSE    .76 TRUE SD    1.61  SEPARATION  2.12  Person RELIABILITY  .82 |
| S.E. OF Person MEAN = .31                                                   |
-------------------------------------------------------------------------------
Person RAW SCORE-TO-MEASURE CORRELATION = .97
CRONBACH ALPHA (KR-20) Person RAW SCORE "TEST" RELIABILITY = .87  SEM = 1.86
STANDARDIZED (50 ITEM) RELIABILITY = .92
```

Figure 3. Summary of rasch person statistics for analytical thinking assessment

Person fit statistics further reinforced the model's robustness. Among the 32 non-extreme respondents, the average INFIT MNSQ was 1.00 and the OUTFIT MNSQ was 1.10 both within the acceptable range of 0.5 to 1.5 (Linacre, 2023) indicating that student responses aligned well with the Rasch model shown in FIGURE 3. These results support the unidimensionality of the analytical thinking construct being measured, strengthening the validity of inferences drawn from the instrument. Only one respondent (Person 21P, 2.9%) displayed misfit behavior, likely due to guessing or topic-specific difficulty rather than a fundamental lack of analytical skill. The results of the person fit analysis for non-extreme respondents can be seen in Figure 4.

```
    SUMMARY OF 32 MEASURED (NON-EXTREME) Person
-------------------------------------------------------------------------------
|          TOTAL                         MODEL         INFIT        OUTFIT    |
|          SCORE      COUNT     MEASURE   S.E.      MNSQ   ZSTD   MNSQ   ZSTD |
|-----------------------------------------------------------------------------|
| MEAN       8.9       20.0       -.30     .56      1.00   -.10   1.10    .01 |
|  SEM        .8         .0        .23     .02       .03    .13    .08    .17 |
| P.SD       4.5         .0       1.26     .12       .17    .72    .44    .93 |
| S.SD       4.5         .0       1.28     .12       .17    .73    .45    .94 |
| MAX.      19.0       20.0       3.17    1.03      1.51   1.75   2.38   1.90 |
| MIN.       2.0       20.0      -2.41     .48       .71  -1.69    .63  -1.58 |
|-----------------------------------------------------------------------------|
| REAL RMSE    .59 TRUE SD    1.11  SEPARATION  1.88  Person RELIABILITY  .78 |
|MODEL RMSE    .57 TRUE SD    1.12  SEPARATION  1.98  Person RELIABILITY  .80 |
| S.E. OF Person MEAN = .23                                                   |
-------------------------------------------------------------------------------
  MAXIMUM EXTREME SCORE:      2 Person 5.7%
  MINIMUM EXTREME SCORE:      1 Person 2.9%
```

Figure 4. Summary of person fit statistics for non-extreme respondents

The wide spread of student abilities (range = 8.84 logits) reflects substantial heterogeneity in analytical thinking development, consistent with cognitive load theory (Sweller et al., 2011) and other studies suggesting that complex reasoning develops at varied rates based on students' prior knowledge, metacognitive skills, and instructional experiences (Lombardi 2023). This heterogeneity highlights the importance of differentiated instructional strategies and the potential of the Rasch model to inform targeted interventions.

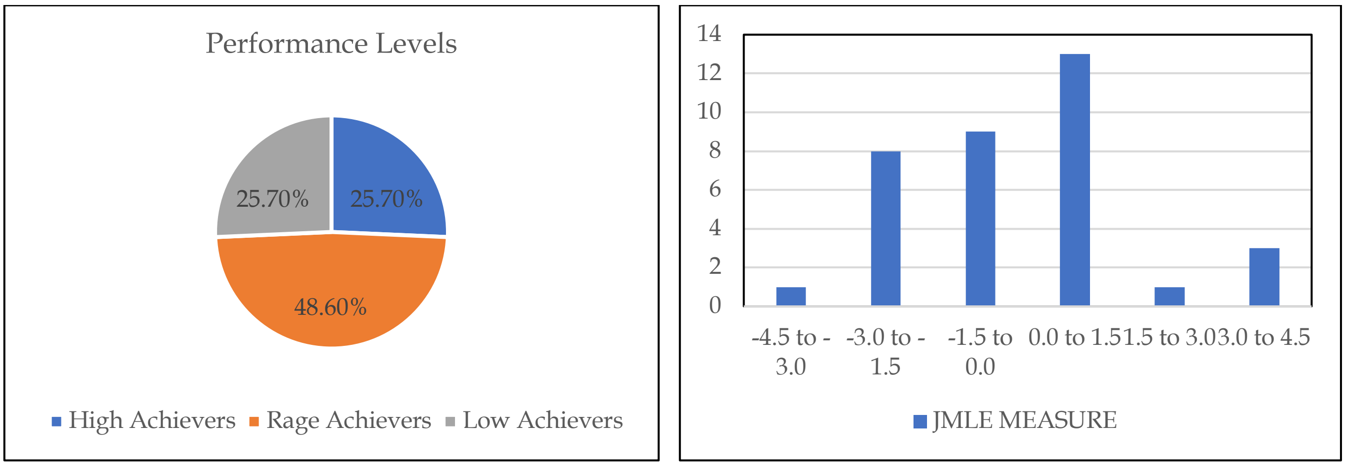
In addition, the results reinforce the value of using Rasch-based diagnostics in combination with technology-enhanced learning tools to support analytical skill development. Previous research has demonstrated that instructional innovations such as socio scientific inquiry (Noris et al. 2025), flipped-book-based learning (Sari et al. 2025), and simulation-based environments (Thabvithorn and Samat 2022) can enhance analytical engagement and performance. Notably, computational tools like coding education have been shown to improve sub-skills critical to analytical thinking, such as sorting, classification, and comparison (Kocaman 2023).

Overall, the high reliability and model fit values observed in this study provide compelling evidence that the instrument is both psychometrically sound and instructionally informative. Its use in classroom settings can support both formative assessment and curriculum alignment, particularly when paired with pedagogical strategies that address diverse cognitive profiles

Distribution and Dimensions of Analytical Thinking Abilities

The analytical thinking abilities of the 35 participating students displayed substantial variation, ranging from -4.43 to +4.41 logits a total span of 8.84 logits can be seen FIGURE 3. This wide range indicates significant diversity in cognitive skill levels within the group and supports the need for differentiated instructional approaches (Lombardi 2023; Tomić 2021). The average person ability can be seen FIGURE 3 (-0.15 logits) was slightly lower than the item mean (0.00 logits), indicating that the test items were moderately more challenging than the average student's ability. Such misalignment, though small, suggests opportunities to refine the item difficulty to better target the majority of learners (Wang and Shan 2025).

As shown in FIGURE 5, the distribution of abilities allowed the classification of students into three achievement categories: high, moderate, and low performers. Notably, 8.6% of students were impacted by extreme scores two achieving perfect scores (ceiling effect; 23L;24P) and one scoring zero (floor effect; 03P) shown in FIGURE 6. These extremes further emphasize the need to broaden the item difficulty range in future versions of the test.



(a) (b)

Figure 5. Analytical thinking ability distribution: **(a)** performance levels and **(b)** Rasch-based ability measures.

Overall, the majority of physics education students at Universitas Pendidikan Indonesia (UPI) in this study were classified as average achievers (48.6%) indicating that, in general, their analytical thinking abilities remain at a moderate level, this distribution pattern aligns with findings from Dewi et al. (2024); Marisda et al. (2024), who also observed that approximately half of Indonesian physics students demonstrated moderate analytical thinking levels, suggesting a systemic need for instructional enhancement. This finding suggests a clear need to strengthen instructional strategies that focus on problem-solving, reflective reasoning, and higher-order thinking skills within the physics education curriculum. These results underscore the importance of systematic instructional improvements to foster students' analytical competence. Given the increasing demands of 21st-century education, workplace problem-solving, and global competition, enhancing students' analytical thinking is essential. Strategic interventions—such as problem-based learning, structured argumentation tasks, and formative diagnostic assessments—could support the development of higher-order cognitive abilities among future physics educators.

```
TABLE 17.1 C:\Users\user\Desktop\Rasch.prn        ZOU156WS.TXT  Jun 01 2025 12:40
INPUT: 35 Person  20 Item  REPORTED: 35 Person  20 Item  2 CATS MINISTEP 5.9.2.0
--------------------------------------------------------------------------------
Person: REAL SEP.: 2.07  REL.: .81 ... Item: REAL SEP.: 1.39  REL.: .66

        Person STATISTICS:  MEASURE ORDER
```

ENTRY NUMBER	TOTAL SCORE	TOTAL COUNT	JMLE MEASURE	MODEL S.E.	INFIT MNSQ	INFIT ZSTD	OUTFIT MNSQ	OUTFIT ZSTD	PTMEASUR-AL CORR.	PTMEASUR-AL EXP.	EXACT MATCH OBS%	EXACT MATCH EXP%	Person
23	20	20	4.41	1.83	MAXIMUM MEASURE				.00	.00	100.0	100.0	23L
24	20	20	4.41	1.83	MAXIMUM MEASURE				.00	.00	100.0	100.0	24P
25	19	20	3.17	1.03	1.04	.34	1.04	.44	.06	.14	95.0	95.0	25L
26	16	20	1.54	.58	.95	-.05	.85	-.17	.34	.26	80.0	79.9	26L
19	15	20	1.23	.54	.81	-.72	.66	-.87	.55	.29	75.0	74.9	19L
4	14	20	.96	.51	.86	-.61	.73	-.86	.51	.31	70.0	70.6	04P
31	14	20	.96	.51	.96	-.13	.98	.05	.35	.31	70.0	70.6	31P
18	13	20	.70	.50	.71	-1.69	.63	-1.58	.70	.33	90.0	67.3	18P
1	12	20	.47	.49	1.00	.03	.98	-.04	.35	.34	65.0	65.5	01P
5	12	20	.47	.49	.89	-.62	.88	-.49	.47	.34	75.0	65.5	05L
10	12	20	.47	.49	.79	-1.31	.73	-1.33	.61	.34	75.0	65.5	10P
11	12	20	.47	.49	.83	-1.01	.77	-1.09	.56	.34	75.0	65.5	11L
15	12	20	.47	.49	.93	-.37	.90	-.40	.43	.34	75.0	65.5	15L
14	11	20	.23	.48	.93	-.42	.89	-.53	.45	.35	70.0	65.0	14L
32	11	20	.23	.48	.91	-.56	.90	-.51	.46	.35	70.0	65.0	32P
9	10	20	.01	.48	.79	-1.32	.78	-1.32	.61	.35	80.0	66.0	09P
12	10	20	.01	.48	.91	-.52	.90	-.55	.47	.35	70.0	66.0	12P
13	9	20	-.22	.48	.96	-.16	1.04	.28	.37	.35	75.0	67.0	13L
17	9	20	-.22	.48	1.12	.73	1.13	.72	.21	.35	65.0	67.0	17P
8	8	20	-.45	.49	.91	-.47	.88	-.51	.47	.35	75.0	68.1	08P
30	8	20	-.45	.49	1.16	.91	1.18	.87	.15	.35	55.0	68.1	30P
33	8	20	-.45	.49	.97	-.11	.92	-.31	.40	.35	65.0	68.1	33P
34	8	20	-.45	.49	.99	-.01	.94	-.20	.38	.35	65.0	68.1	34P
16	7	20	-.69	.50	.92	-.37	.85	-.53	.46	.34	75.0	69.1	16L
29	6	20	-.95	.52	.95	-.15	.87	-.36	.41	.33	80.0	71.0	29P
21	5	20	-1.23	.54	1.51	1.75	1.81	1.87	-.38	.31	75.0	74.9	21P
20	4	20	-1.55	.58	.89	-.24	.66	-.66	.48	.29	80.0	79.9	20P
6	3	20	-1.92	.65	1.16	.50	1.73	1.21	-.06	.26	85.0	84.9	06P
7	3	20	-1.92	.65	1.14	.47	1.40	.79	.02	.26	85.0	84.9	07P
22	3	20	-1.92	.65	1.35	.91	2.38	1.90	-.40	.26	85.0	84.9	22P
28	3	20	-1.92	.65	1.18	.55	2.32	1.83	-.19	.26	85.0	84.9	28P
35	3	20	-1.92	.65	1.18	.56	1.50	.93	-.05	.26	85.0	84.9	35L
2	2	20	-2.41	.76	1.19	.51	1.73	1.02	-.16	.22	90.0	89.9	02L
27	2	20	-2.41	.76	1.01	.21	1.22	.53	.14	.22	90.0	89.9	27L
3	0	20	-4.43	1.83	MINIMUM MEASURE				.00	.00	100.0	100.0	03P
MEAN	9.3	20.0	-.15	.67	1.00	-.10	1.10	.01			76.6	73.5	
P.SD	5.2	.0	1.79	.37	.17	.72	.44	.93			8.9	9.0	

Figure 6. Person Measure Order from Rasch Analysis

In terms of indicator-level performance, analysis revealed that students performed best in "Finding and Precisely Identifying Relational Patterns" (48.2%), followed by "Identifying Problems" (46.7%) can be seen in FIGURE 7. This suggests that students are relatively proficient in recognizing connections and decomposing complex physics problems, likely due to procedural emphasis in traditional instruction (Udonsathian and Worapun 2024). In contrast, lower scores were observed in "Summarizing Main Ideas" (44.7%) and "Identifying and Evaluating Reasoning Errors" (43.5%). These dimensions require higher-order metacognitive abilities such as abstraction, evaluation, and synthesis, which are often underdeveloped in physics curricula (Dewi et al. 2024; Özsoy-Güneş et al. 2015).

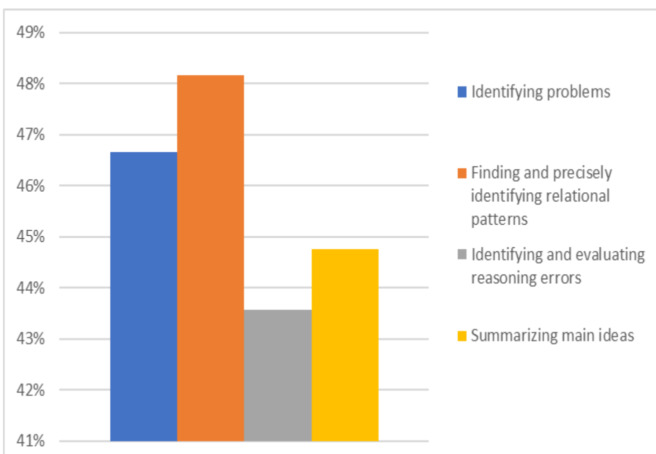


Figure 7. Percentage of Correct Responses by Analytical Thinking Indicator

This performance imbalance points to a need for more integrative instructional approaches that not only emphasize conceptual mastery and problem-solving but also cultivate reflective reasoning and evaluative thinking. Studies (Anthonysamy et al. 2024; Mohareb and Al Khraisha 2025) have demonstrated that incorporating dialogic reasoning, peer critique, and structured argumentation into science education can significantly improve performance in these more complex analytical domains.

Gender Differences in Analytical Thinking

A gender-based breakdown revealed a moderate performance gap: male students scored higher on average (0.15 logits) than female students (-0.31 logits), with a mean ability difference of 0.46 logits shown in TABLE 3. This magnitude of gender difference is consistent with meta-analyses in STEM analytical assessment (Anyafulude 2013; Marín-Marín et al. 2021; Samaradiwakera-Wijesundara 2022; Tosyali and Aktas 2021), which reported effect sizes ranging from 0.3 to 0.5 in similar contexts. As shown in Figure 8, this discrepancy manifested most clearly among low achievers, where 35% of female students fell into this group compared to only 13.3% of males. Conversely, males had a higher proportion of high achievers (33.3%) than females (20%).

Table 3. Analytical Thinking Performance by Gender

Measure	Male (n=15)	Female (n=20)	Difference
Mean Logits	0.15	-0.31	0.46
Standard Deviation	1.65	1.88	-
Range	-2.41 to 4.41	-4.43 to 4.41	-
High Achievers (%)	33.3% (5/15)	20.0% (4/20)	+13.3%
Average Achievers (%)	53.3% (8/15)	45.0% (9/20)	+8.3%
Low Achievers (%)	13.3% (2/15)	35.0% (7/20)	-21.7%

Although these differences were not statistically tested in this study, the patterns observed align with existing literature suggesting that gender-based performance differences in analytical thinking may arise from factors such as stereotype threat, academic self-concept, and prior exposure to cognitively demanding tasks (Çoksan and Yilmaz 2024; Early et al. 2020; Sunyík and Čavojová 2023). The importance of fostering physics identity and sustained engagement particularly for female students has been emphasized as a key factor in closing achievement gaps in STEM learning (Irdalisa et al. 2024; Sultan et al. 2024). These findings reinforce the call for gender-sensitive instructional design and assessment approaches that account for the broader sociocultural and motivational factors shaping student performance in analytical domains.

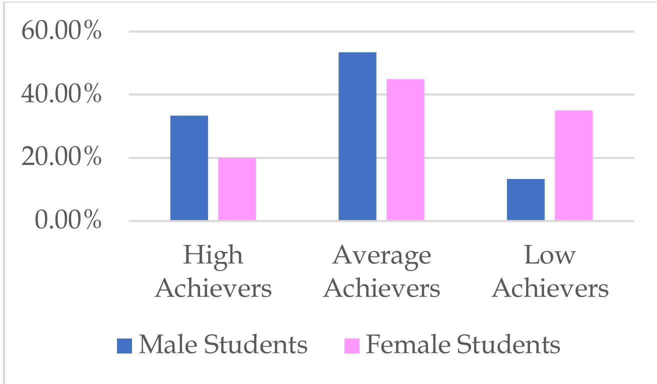


Figure 8. Performance distribution by gender

Implications and Recomendations for Physics Education

The substantial heterogeneity in analytical thinking abilities observed in this study has important implications for physics education. The wide spread of student abilities (range = 8.84 logits) reflects substantial differences in analytical thinking development, consistent with cognitive load theory (Sweller et al., 2011) and studies suggesting that complex reasoning develops at varied rates based on students' prior knowledge, metacognitive skills, and instructional experiences (Lombardi 2023).

This heterogeneity highlights the importance of differentiated instructional strategies and the potential of diagnostic analysis to inform targeted interventions. The results support the value of using assessment-based diagnostics in combination with technology-enhanced learning tools to support analytical skill development. Previous research has demonstrated that instructional innovations such as socio-scientific inquiry (Noris et al. 2025), flipped-book-based learning (Sari et al. 2025), and simulation-based environments (Thabvithorn and Samat 2022) can enhance analytical engagement and performance.

The identification of three distinct performance levels (high, average, and low achievers) suggests that instructional approaches should be tailored to meet the specific needs of each group. High achievers may benefit from advanced problem-solving challenges and independent inquiry projects, while low achievers may require more scaffolded instruction and foundational skill development.

Based on the findings that the majority of physics education students at Universitas Pendidikan Indonesia were classified as average achievers in analytical thinking, targeted educational improvements are warranted. Firstly, curriculum design should be enriched with higher-order tasks that foster critical analysis, conceptual reasoning, and metacognitive reflection. Integrating inquiry-based learning, argument-driven inquiry, and reflective assessment methods has been shown to significantly improve analytical thinking in science education (Anthonysamy et al. 2024; Udonsathian and Worapun 2024). Secondly, students who fall into the low-achiever category require differentiated instructional support, including scaffolding strategies, feedback-rich environments, and explicit modeling of reasoning processes (Dewi et al. 2024; Kurrer 2016; Marisda et al. 2024; Puvia et al. 2020).

The integration of technology-enhanced learning environments such as simulation-based modules, flipped learning, and scenario-based tasks can also play a crucial role in strengthening analytical thinking by offering interactive, cognitively demanding experiences (Setiaji et al. 2023; Thabvithorn and Samat 2022). Furthermore, the gender-based discrepancies observed in this study highlight the importance of adopting gender-sensitive pedagogical approaches that promote equitable opportunities and mitigate potential stereotype threats, which are known to affect female performance in STEM domains (Irdalisa et al. 2024; Sultan et al. 2024).

Additionally, the use of Rasch-based diagnostics in regular classroom assessment can provide evidence-based feedback to guide instruction, monitor cognitive growth, and ensure alignment between student abilities and task difficulty (Altıntaş and Kutlu, 2020; Linacre, 2023). Finally, future research should extend this study by employing larger, more diverse samples and longitudinal designs to track the development of analytical thinking over time and in response to specific educational interventions (Noris et al. 2025; Wang and Shan 2025).

Conclusion

This study examined the analytical thinking abilities of physics education students using Rasch measurement theory, revealing substantial heterogeneity in performance across the sample. The instrument demonstrated strong psychometric properties, enabling reliable distinction of students across three performance levels: high achievers, average achievers, and low achievers. Analysis of analytical thinking dimensions showed that students performed best in identifying relational patterns and identifying problems, while struggling with summarizing main ideas and evaluating reasoning errors, indicating underdevelopment in higher-order metacognitive skills. Gender-based analysis revealed that male students outperformed females, with females disproportionately represented among low achievers, suggesting the influence of sociocultural and motivational factors. These findings underscore the critical need for differentiated instructional strategies tailored to diverse ability levels, curriculum enrichment with higher-order cognitive tasks, scaffolded support for struggling students, and gender-sensitive pedagogical approaches to ensure equitable learning opportunities. The Rasch modeling approach provided a statistically rigorous and instructionally actionable framework for diagnostic assessment, demonstrating its value for informing evidence-based curriculum design, targeted interventions, and systematic efforts to enhance analytical thinking development in physics education. Future research should employ larger and more diverse samples with longitudinal designs to track the development of analytical thinking over time and evaluate the effectiveness of specific instructional interventions in addressing identified performance gaps.

Acknowledgments

The authors would like to thank the Institute for Research and Community Service (LPPM), Universitas Pendidikan Indonesia, for research support and facilitation under the Annual Work Plan and Budget Fiscal Year 2025. The authors also appreciate the participating physics education students for their cooperation during the data collection process.

Author Contributions

Conceptualization, A.A. and M.R.D.S.; methodology, A.A., M.R.D.S., and N.; software, A.A.; validation, A.A., N., and M.R.D.S.; formal analysis, A.A.; investigation, A.A., F.N.A., and S.A.; resources, A.A.; data curation, A.A. and M.R.D.S.; writing—original draft preparation, A.A.; writing—review and editing, A.A., M.R.D.S., N., F.N.A., and S.A.; supervision, A.A. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by the Annual Work Plan and Budget (*Rencana Kerja dan Anggaran Tahunan*) of the Institute for Research and Community Service, Universitas Pendidikan Indonesia, Fiscal Year 2025, under Rector Decree Number 443/UN40/PT.01.02/2025. The APC was funded by the same source.

Conflicts of Interest

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

Adawiyah, R., E. Istiyono, I. Wilujeng, and S. Hardiyanti. 2020. "Development of an Instrument Measuring the Multi Representation Ability of Senior High School Students." in *Journal of Physics: Conference Series*. Vol. 1440, edited by W. A., P. null, A. N.A., and D. M.I.B.M. Physics Education, Universitas Negeri Yogyakarta, Sleman, Indonesia: Institute of Physics Publishing.

Altıntaş, Özge, and Ömer Kutlu. 2020. "Investigating Measurement Invariance of Ankara University Foreign Students Selection Test According to Latent Class and Rasch Model." *Egitim ve Bilim* 45(203):287–308. doi:10.15390/EB.2020.8685.

Anthonysamy, Lilian, Poovilashini Sugendran, Lim Ooi Wei, and Teoh Sian Hoon. 2024. "An Improved Metacognitive Competency Framework to Inculcate Analytical Thinking among University Students." *Education and Information Technologies* 29(17):22475–97. doi:10.1007/s10639-024-12678-z.

Anyafulude, Joy Chinelo. 2013. "Effects of Problem-Based and Discovery-Based Instructional Strategies on Students' Academic Achievement in Chemistry." *Journal of Educational and Social Research* 3(6):105–12. doi:10.5901/jesr.2013.v3n6p105.

Bond, T. G., & Fox, C. M. (2015). *Applying the Rasch model: Fundamental measurement in the human sciences* (3rd ed.). New York, NY: Routledge.

Brookhart, Susan M. 2010. "How to Assess Higher-Order Thinking Skills in Your Classroom." *Ascd* 159.

Çoksan, Sami, and Aysenur Didem Yilmaz. 2024. "Focusing on Fake News' Contents: The Association between Ingroup Identification, Perceived Outgroup Threat, Analytical-Intuitive Thinking and Detecting Fake News." *Analyses of Social Issues and Public Policy* 24(1):102–32. doi:10.1111/asap.12371.

Creswell, John W., and J. David Creswell. 2018."Research Design: Qualitative, Quantitative, and Mixed Methods Approaches - John W. Creswell, J. David Creswell - Google Books." https://books.google.co.id/books?hl=en&lr=&id=335ZDwAAQBAJ&oi=fnd&pg=PT16&dq=.+Creswell,+J.+W.+(2014)+Research+Design:+Qualitative,+Quantitative,+and+Mixed+Methods+Approaches&ots=YExQLJrvuK&sig=tmrcZzcfQLgDJTmVMsf7BeVtSw0&redir_esc=y#v=onepage&q=. Creswel.

Demir, Engin. 2022. "An Examination of High School Students' Critical Thinking Dispositions and Analytical Thinking Skills." *Journal of Pedagogical Research* 6(4):190–200. doi:10.33902/JPR.202217357.

Dewi, Sartika Sari, Andi Muhammad Irfan Taufan Asfar, Andi Muhamad Iqbal Akbar Asfar, and Andi Nurannisa. 2024. "Traditional Game Strategy Bugis Ma'benteng Integrated 4C Skills in Improving Analytical Thinking Ability." in *AIP Conference Proceedings*. Vol. 2987, edited by T. J.T., J. I., and L. M.S. Department of Educational Technology, University Muhammadiyah Bone, Abu Dg Pasolong St., Sulawesi Selatan, Watampone, 92713, Indonesia: American Institute of Physics.

Early, Spencer, Seyedmohammadmahdi Mirhoseini, Nour El Shamy, and Khaled Hassanein. 2020. "Relying on System 1 Thinking Leaves You Susceptible to the Peril of Misinformation." Pp. 42–48 in *Lecture Notes in Information Systems and Organisation*. Vol. 43, edited by D. F.D., R. R., vom B. J., L. P., R. A.B., and F. T. DeGroote School of Business, McMaster University, Hamilton, Canada: Springer Science and Business Media Deutschland GmbH.

Fitriani, Fitriani, and Wirawan Fadly. 2022. "Level Analysis and Supporting Factors of Thinking Ability Analytical in Solving Problem Based Problems Reviewed From the Learning Styles of Students." *INSECTA: Integrative Science Education and Teaching Activity Journal* 3(2):194–204. doi:10.21154/insecta.v3i2.5318.

Greenholts, Moshe, and Igor M. Verner. 2020. "Fostering Students' Analytical Thinking and Applied Mathematical Skill through 3D Design and Printing." Pp. 563–67 in *IEEE Global Engineering Education Conference, EDUCON*. Vols. 2020-April, edited by C. A., A. G.R., and R. T. Technion - Israel Institute of Technology, Faculty of Education in Science and Technology, Haifa, Israel: IEEE Computer Society.

Hajkowicz, Stefan, Conrad Sanderson, Sarvnaz Karimi, Alexandra Bratanova, and Claire Naughtin. 2023. "Artificial Intelligence Adoption in the Physical Sciences, Natural Sciences, Life Sciences, Social Sciences and the Arts and Humanities: A Bibliometric Analysis of Research Publications from 1960-2021." *Technology in Society* 74. doi:10.1016/j.techsoc.2023.102260.

Hidayat, Riyan, Irham Nugroho, Zamzami Zainuddin, and Tony Anak Ingai. 2024. "A Systematic Review of Analytical Thinking Skills in STEM Education Settings." *Information and Learning Science* 125(7–8):565–86. doi:10.1108/ILS-06-2023-0070.

Hong, Bright. 2022. "Initial Task Engagement: Unlocking the Value of Fit and Non-Fit to Improve Audit Judgments." *Accounting Review* 97(6):327–56. doi:10.2308/TAR-2019-0607.

Irdalisa, Irdalisa, Paidi Paidi, Rashmi Ranjan Panigrahi, and Erlia Hanum. 2024. "Project-Based Learning on STEAM-Based Student's Worksheet with Ecoprint Technique: Effects on Student Scientific Reasoning and Creativity." *Jurnal Inovasi Pendidikan IPA* 10(2):222–36. doi:10.21831/JIPI.V10I2.77676.

Karla, Divya, Vijay Kumar Pandey, Prachi Rastogi, and Sunil Kumar. 2022. "A Comprehensive Review on Significance of Problem-Solving Abilities in Workplace." *World Journal of English Language* 12(3):88–95. doi:10.5430/wjel.v12n3p88.

Kocaman, Berrak. 2023. "The Effect of Coding Education on Analytical Thinking of Gifted Students." *International Journal of Educational Methodology* 9(1):95–106. doi:10.12973/ijem.9.1.95.

Kurrer, Karl Eugen. 2016. "Analytisches Denken und spielerische Baustatik: 20 Jahre Weihnachtspreisaufgabe in „Stahlbau“.” *Stahlbau* 85(4):241–241. doi:10.1002/STAB.201690051.

Levin, Laura, and Igor M. Verner. 2020. “Fostering Students’ Analytical Thinking and Applied Mathematical Skills through 3D Design and Printing.” Pp. 145–49 in *IEEE Global Engineering Education Conference, EDUCON*. Vols. 2020-April, edited by C. A., A. G.R., and R. T. Technion - Israel Institute of Technology, Faculty of Education in Science and Technology, Haifa, Israel: IEEE Computer Society.

Lombardi, Doug. 2023. “On the Horizon: The Promise and Power of Higher Order, Critical, and Critical Analytical Thinking.” *Educational Psychology Review* 35(2). doi:10.1007/s10648-023-09763-z.

Maqruf, Agus, Tatang Herman, Lathiful Anwar, Agung Wicaksono, and Dwi Warli. 2024. “Students’ Analytical Thinking Process in Solving Sets Problems in Terms of The Characteristics of Pseudo Thinking.” *Acta Scientiae* 26(4):1–24. doi:10.17648/acta.scientiae.8099.

Marín-Marín, José Antonio, Antonio José Moreno-Guerrero, Pablo Dúo-Terrón, and Jesús López-Belmonte. 2021. “STEAM in Education: A Bibliometric Analysis of Performance and Co-Words in Web of Science.” *International Journal of STEM Education* 8(1).

Marisda, Dewi Hikmah, Nurlina Nurlina, Ma’Ruf Ma’ruf, Rahmawati Rahmawati, Reski Idamayanti, and Muhammad Akbar. 2024. “Challenges in Secondary School Education: Profile of Physics Students’ Critical Thinking Skills.” *Journal of Education and Learning* 18(3):1099–1106. doi:10.11591/edulearn.v18i3.21666.

Mohareb, Triza William Azmy, and Samah Nimer Al Khraisha. 2025. “The Effectiveness of Blackboard Wikis and the KWL Strategy in Promoting Analytical, Creative Thinking and Academic Success in Higher Education.” *Smart Learning Environments* 12(1). doi:10.1186/s40561-025-00397-y.

Nieto-Jalil, José M., Jorge Lozano-Aponte, and Julian Alejandro Yunes Rojas. 2024. “Revolutionizing Chemistry in the Classroom: A University Educational Experience with the Power of MATLAB.” in *IEEE Global Engineering Education Conference, EDUCON*. Tecnologico de Monterrey, School of Engineering and Sciences, Puebla, Mexico: IEEE Computer Society.

Noris, M., Sajidan Sajidan, Sulistyo Saputro, and Sri Yamtinah. 2025. “Effectiveness of Innovator’s Disruptive-Based Socioscientific Learning (Innova-DB2SL) to Improve Analytical Thinking and Entrepreneurial Skills.” *International Journal of Innovative Research and Scientific Studies* 8(3):2512–21. doi:10.53894/ijirss.v8i3.7043.

Özsoy-Güneş, Zeliha, İbrahim Güneş, Yasemin Derelioğlu, and Fatma Gülay Kırbaşlar. 2015. “The Reflection of Critical Thinking Dispositions on Operational Chemistry and Physics Problems Solving of Engineering Faculty Students.” *Procedia - Social and Behavioral Sciences* 174:448–56. doi:10.1016/j.sbspro.2015.01.688.

Puvia, Elisa, Vito Monteleone, Giovanni Fulantelli, and Davide Taibi. 2020. “Facing the Appeal of Social Networks: Methodologies and Tools to Support Students towards a Critical Use of the Web.” Pp. 567–73 in *CSEDU 2020 - Proceedings of the 12th International Conference on Computer Supported Education*. Vol. 1, edited by L. H.C., Z. S., and U. J. Consiglio Nazionale delle Ricerche, Istituto per le Tecnologie Didattiche, Palermo, Italy: SciTePress.

Rasch, G. (1960). ***Probabilistic models for some intelligence and attainment tests.*** Copenhagen, Denmark: Danish Institute for Educational Research.

Samaradiwakera-Wijesundara, Charmika. 2022. “Intersectionality and/or Multiple Consciousness: Re-Thinking the Analytical Tools Used to Conceptualise and Navigate Personhood.” *Agenda* 36(4):198–205. doi:10.1080/10130950.2022.2184933.

Sari, Sri Adelila, Ratna Sari Dewi, Kana Saputra, Agus Kembaren, Hanisah Hasibuan, and Corrienna Abdul Talib. 2025. “Integration of Analytical Chemistry Flipbooks Based on Project-Based Learning in Improving Critical Thinking Skills and Scientific Literacy To Support Sdg-4.” *Jurnal Pendidikan IPA Indonesia* 14(1):59–69. doi:10.15294/jpii.v14i1.21038.

Setiaji, Bayu, Endang Tri Adiningsih, Zulfa Lutfi Anisa, and Yashinta Putri Sekarini. 2023. “E-PBL Physics Online Module to Enhance Students’ Analytical Thinking Skill in COVID-19 Pandemic Era.” in *AIP Conference Proceedings*. Vol. 2556, edited by A. N.A., P. K.R., S. H., F. F., and K. P.C. Physics Education, Faculty of Mathematics and Science, Universitas Negeri Yogyakarta, Jl. Colombo No.1, Karang Malang, Depok, Sleman, Yogyakarta, 55281, Indonesia: American Institute of Physics Inc.

Sultan, Mubashir, Alan N. Tump, Nina Ehmann, Philipp Lorenz-Spreen, Ralph Hertwig, Anton Gollwitzer, and Ralf H. J. M. Kurvers. 2024. “Susceptibility to Online Misinformation: A Systematic Meta-Analysis of Demographic and Psychological Factors.” *Proceedings of the National Academy of Sciences of the United States of America* 121(47). doi:10.1073/pnas.2409329121.

Sunyík, Viktória, and Vladimíra Čavojová. 2023. “Alternative Medicine, COVID-19 Conspiracies, and Other Health-Related Unfounded Beliefs: The Role of Scientific Literacy, Analytical Thinking, and Importance of Epistemic Rationality.” *Studia*

Psychologica 65(3):246–61. doi:10.31577/sp.2023.03.878.

Surin, Supansa, and Suntonrapot Damrongpanit. 2024. "Quantifying Influence: Propensity Score Matching Unravels the True Effect Sizes of Learning Management Models on Students' Analytical Thinking." *European Journal of Educational Research* volume-13-(volume-13-issue-4-october-2024):1535–53. doi:10.12973/eu-jer.13.4.1535.

Thabvithorn, Chayaphorn, and Charuni Samat. 2022. "Development of Web-Based Learning with Augmented Reality (AR) to Promote Analytical Thinking on Computational Thinking for High School." Pp. 125–33 in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*. Vol. 13449 LNCS, edited by H. Y.-M., C. S.-C., B. J., and S. F.E. Educational in Science and Technology, Faculty of Education, Khon Kaen University, Khon Kaen, Thailand: Springer Science and Business Media Deutschland GmbH.

Tomić, Taeda. 2021. "The Distinction Between False Dilemma and False Disjunctive Syllogism." *Informal Logic* 41(4):607–39. doi:10.22329/IL.V41I4.6233.

Tosyali, Furkan, and Busra Aktas. 2021. "Does Training Analytical Thinking Decrease Superstitious Beliefs? Relationship between Analytical Thinking, Intrinsic Religiosity, and Superstitious Beliefs." *Personality and Individual Differences* 183. doi:10.1016/j.paid.2021.111122.

Udonsathian, T., and W. Worapun. 2024. "Enhancing Analytical Thinking in Grade 8 Science Education: Integrating 5E Inquiry-Based and 5W1H Techniques." *International Journal of Advanced and Applied Sciences* 11(5):62–69. doi:10.21833/ijaas.2024.05.007.

Wang, Rui, and Zhilong Shan. 2025. "DEKT: Difficulty Representation Enriched Knowledge Tracing." Pp. 33–47 in *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* . Vol. 15388 LNAI, edited by S. Q.Z., Z. X., W. J., M. C., D. G., J. J., Z. W.E., M. Y., and M. W. School of Computer Science, South China Normal University, Guangzhou, 510631, China: Springer Science and Business Media Deutschland GmbH.

Wiyarsi, Antuni, Atina Rizanatul Fachriyah, Didi Supriadi, and Muhd Ibrahim Bin Muhamad Damanhuri. 2019. "A Test of Analytical Thinking and Chemical Representation Ability on 'Rate of Reaction' Topic." *Cakrawala Pendidikan* 38(2):228–42. doi:10.21831/cp.v38i2.23062.

Wright, B.D. and Stone, M.H., 1979. *Best test design*. Chicago: MESA Press.