CHEMICALAI-INTEGRATED PROBLEM-BASED LEARNING VS GUIDED INQUIRY: ENHANCING STUDENTS' SCIENTIFIC ARGUMENTATION SKILLS IN REACTION RATES

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Abstract. *Chemistry education involves complex representations often hindering scientific argumentation. This study compares the effectiveness of Problem-Based Learning (PBL) and Guided Inquiry (GI) integrated with ChemicalAI in enhancing students scientific argumentation skills on reaction rates. The research employed a quasi-experimental method with a pretest-posttest non-equivalent control group design. Data were analyzed using the Rasch Model for instrument validation and Analysis of Covariance (ANCOVA) for hypothesis testing. Rasch analysis confirmed the high reliability of the instrument while identifying reasoning as the most challenging component for the students. Based on the research findings, it was found that students who participated in the PBL method performend significantly better than students who participated in the GI method. This demonstrates superior performance in formulating claim, evidence and reasoning. Furthermore, the integration of Chemical-AI into PBL effectively facilitates the development of complex scientific arguments based on experimental data.*

Keywords: *ChemicalAI, Problem-Based Learning, Guided Inquiry, Scientific Argumentation, Reaction Rates*

INTRODUCTION

Rapid advances in science and technology have necessitated a shift in the education system toward 21st-century competencies. UNESCO (2017) [1] emphasizes that education today focuses on training students in essential skills, including critical thinking [2], problem solving [2], and especially scientific argumentation [3]. In chemistry education, scientific reasoning skills are a core competency [4], because this skill requires students not only to understand concepts, but also to construct arguments, present evidence, and develop logical reasoning based on experimental data [5]. Therefore, Indonesia's latest curriculum explicitly focuses on developing these skills in order to foster scientifically literate individuals.

However in reality, many students still struggle to develop strong scientific argumentation skills. Research by Putri et al., (2025) [6] and Zaroh et al. (2022) [7] indicates that students often have difficulty formulating specific statements and supporting them with valid scientific evidence. This problem is particulary evident in complex chemistry topics [8] such as chemical reaction rates [9], which encompasses three levels of representation: macroscopic, microscopic, and symbolic [10]. Furthermore, the complex of this topic often makes it difficult for students to engage in the depth scientific discussions, and they to be passive during these discussions, which results in their argumentation skills not yet reaching their full potential [11].

To address this gap, innovative student-centered learning models are required. Problem-Based Learning (PBL) and Guided Inquiry (GI) have emerged as two prominent approaches to enhance students' involvement in scientific practices. While GI focuses on structured investigation [12], PBL emphasizes solving real problems that naturally trigger debates and the need for evidence based arguments [13,14]. Despite their potential, the effectiveness of these models often depends on the availability of appropriate learning media that can provide objective data for students to analyze.

The integration of digital technology, specifically the "ChemicalAI" website developed, offers a transformative solution. By utilizing Artificial Intelligence to convert digital images of experiments into objective quantitative and visual data, ChemicalAI provides the empirical evidence students need to construct high-quality scientific arguments [15,16,17]. However, there is limited empirical evidence comparing whether PBL or GI is more effective in fostering scientific argumentation when integrated with AI-based tools.

Therefore, this study aims to evaluate and compare the effectiveness of ChemicalAI-integrated PBL and GI models on students' scientific argumentation skills in the topic of chemical reaction rates. To provide a more sophisticated and precise analysis than classical statistics, this research utilizes the Rasch Model to ensures that the assessment of students' argumentation skills is objective, linear, and takes into account the difficulty level of the assessment question, thereby aiming to provide a clearer strategic prespective for innovative chemistry education in the digital era.

METHOD

This research employs a quasi-experimental design, with the purpose of this research is to investigate the comparative effects or two learning models: Problem-based learning (PBL) and Guided Inquiry (GI). Both of which are integrated with the Chemical-AI media. The research participants were eleventh grade students from two different classes in Jombang, selected using a cluster sampling technique. One class was assigned as experimental group 1 (PBL-ChemicalAI), while the other class served as experimental group 2 (GI-ChemicalAI). Both groups were taught the same material, reaction rate.

Teaching procedures in both experimental groups, the Chemical media was used as a tool for digital video analysis during laboratory experiments. In the PBL-ChemicalAI group began with a real problem solving scenario that required students to use ChemicalAI to find empirical evidence and formulate their own solutions. In contrast, the GI-ChemicalAI group, students followed a structured inquiry process, in which the teacher provided guiding questions to help students analyze data from ChemicalAI. The integration of ChemicalAI was crucial in both models because it provided the quantitative and visual data necessary for students to construct their scientific arguments.

Research instruments the primary instrument used in this research is the Scientific Argumentation Skills (SAS) test, which consists of five open ended questions. This test is designed based on Sampson's Argument Structure (SAP), which measures students' ability to formulate three main components: claim, evidence, and reasoning [18]. Each question presents a chemical phenomenon related to the topic of reaction rates, requiring students to provide a scientific explanation supported by data. Before being used, the instrument underwent a process of content validity checks by experts in the field of chemistry education.

To provide a comprehensive evaluation of the research findings, data analysis was conducted in two distinct stages: measurement validation using the Rasch model and hypotesis testing inferential statistics.

Measurement Validation (Rasch Model)

First, students' raw scores on the SAS test were analyzed using Rasch Model via the Ministep Rasch Software. This step is crucial to ensure that the instrument functions consistently across all levels of student ability. The analysis focused on:

1. Summary Statistics: To evaluate the reliability of the subjects and the instruments, in order to ensure the consistency of the measurement.
2. Wright Map (Person-Item Map): To compare the distribution of students' argumentation skills on task difficulty.
3. Item Fit (MNSQ & ZSTD): To ensure that the test items function properly and measure a single dimension of argumentation skills.

Hypothesis Testing (SPSS-Ancova)

Following the validation of the measurement model, *Analysis of Covariance*

(ANCOVA) was conducted using SPSS software to compare the effectiveness of the PBL-ChemicalAI and GI-ChemicalAI models. ANCOVA was choses to control for sudents's initial argumentation skills as s covariate, thereby providing a more accurate estimate of the treatment's effect on posttest scores. The statistical significance was set at Sig. < 0.05, and Partial Eta Squared was calculated to determine the effect size of the instructional interventions.

RESULT

Instrument Quality and Measurement Analysis (Rasch Model)

Before evaluating the effectiveness of the instructional model, the quality of the Scientific Argumentation Skills (SAS) instrument was analyzed using the Rasch Model to ensure measurement accuracy [19]. The summary statistics in Table 1 show exceptional reliability indices, with a Person's Coefficient of Reliability of 0.95 and an Item Reliability of 0.96. These values indicate that the instrument exhibits very high consistency in distinguishing students' abilities and that the item difficulty hierarchy has been well defined [20].

Table 1 Summary Statistics of Scientific Argumentation Skills Questions

	Reliability
Person	0,95
Item	0,96
Cronbach Alpha	0.96

The relationship between student ability and question difficulty is further illustrated in the Wright Map. The map shows that these questions cover a wide range of difficulty levels, from the most challenging tasks, such as S1R, S2R, and S3R (the Reasoning component), to more easily understandable questions like S1C and S3C (the Claim component). Most student ability scores are above the question average, indicating that the integration of ChemicalAI successfully supports students in completing argumentative tasks.

Analysis of Item Difficulty and Validity (Item Measure)

The quality of the Scientific Argumentation Skills (SAS) The instrument was then further evaluated using item-measure analysis to determine the difficulty levels of the test items [21]. Based on the logit scores, the test items successfully measured various levels of students' argumentation skills, ranging from easy to highly challenging.

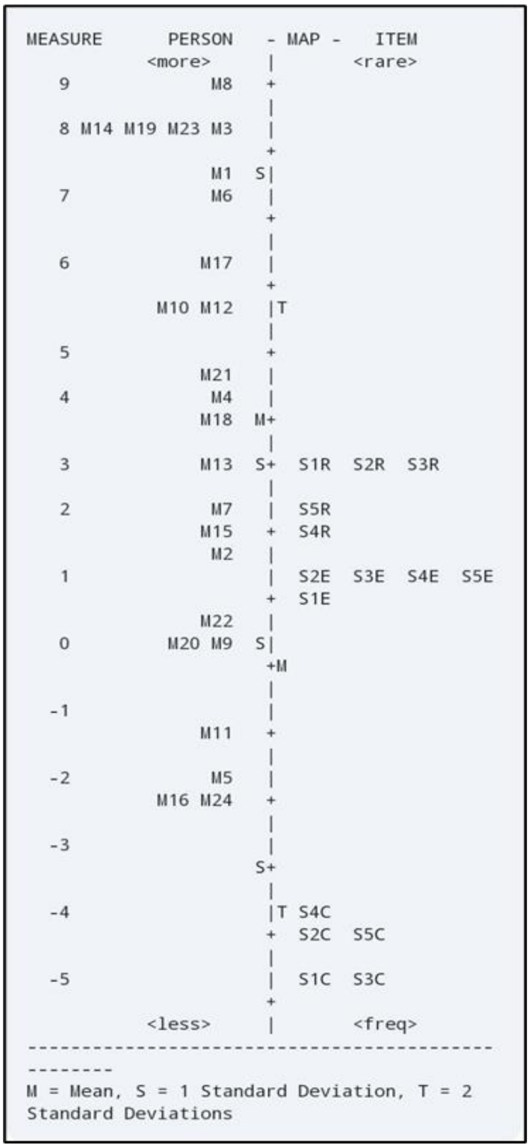

Figure 1 Wright Map and Item Measure of Scientific Argumentation Skills Questions

The Wright Map in Figure 1 and Item Measure in Figure 2 reveal a clear pattern based on the components of Sampson's Argument Pattern (SAP):

1. Most difficult items (Reasoning): The items S1R, S2R, and S3R were identified as the most difficult for students to master, with a measurement score of approximately +3.00 logits. These items require students to develop deep scientific reasoning, which is the most complex stage in the process of argumentation.
2. Moderate difficulty items (Evidence): Items such as S5R, S4R, and the Evidence (E) group (S2E, S3E, S4E, S5E) were positioned in the middle range, with measure values between 0.00 and +2.00 logits. This indicates that students were fairly successful in providing scientific evidence to support their claims.
3. Easiest Items (Claims): The items S1C, S3C, S2C, S5C, and S4C were the easiest for students to answer, with measure values ranging from -4.00 to -5.00 logits. Formulating basic claim was found to be a fundamental task that most students could achieve regardless of their learning model.

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%	ITEM
8	46	24	1.40	.51	1.63	1.60	2.89	2.60	A .86	.87	65.2	78.8	S3E
7	66	24	-4.65	.65	1.72	1.44	.96	.44	B .60	.65	73.9	87.3	S3C
9	40	24	2.85	.48	1.24	.82	1.20	.54	C .87	.83	73.9	74.6	S3R
5	46	24	1.40	.51	1.23	.73	1.14	.42	D .84	.87	73.9	78.8	S2E
12	43	24	2.15	.49	.62	-1.18	1.22	.59	E .87	.85	87.0	77.9	S4R
14	46	24	1.40	.51	1.07	.31	.74	-.36	F .86	.87	82.6	78.8	S5E
3	40	24	2.85	.48	1.02	.17	.73	-.43	G .80	.83	73.9	74.6	S1R
11	46	24	1.40	.51	.99	.09	.88	-.07	H .87	.87	73.9	78.8	S4E
6	40	24	2.85	.48	.92	-.17	.71	-.49	g .81	.83	73.9	74.6	S2R
10	62	24	-3.20	.57	.88	-.22	.53	.07	f .77	.76	87.0	81.7	S4C
15	42	24	2.39	.49	.78	-.60	.62	-.73	e .85	.85	82.6	76.8	S5R
4	63	24	-3.53	.58	.77	-.57	.36	-.13	d .76	.73	82.6	82.1	S2C
2	48	24	.87	.52	.68	-.88	.53	-.79	c .90	.87	87.0	78.6	S1E
13	63	24	-3.53	.58	.67	-.89	.32	-.20	b .77	.73	82.6	82.1	S5C
1	66	24	-4.65	.65	.60	-.86	.24	-.34	a .69	.65	91.3	87.3	S1C
MEAN	50.5	24.0	.00	.53	.99	-.01	.87	.08			79.4	79.5	
P.SD	9.9	.0	2.85	.06	.33	.83	.62	.80			7.0	3.9	

Figure 2 Item Measure of SAS Questions

Furthermore, the Item Fit analysis was conducted to ensure the validity of each item. As illustrated in Figure 2, the Infit and Outfit MNSQ values for most items fell within the acceptable range of 0.5 to 1.5, indicating that the items were productive for measurement and functioned effectively within the Rasch Model [22,23]. For instance, item S4R showed an Infit MNSQ of 0.62, while item S1E was at 0.87, confirming that the assessment items consistently measured students' scientific argumentation skills without significant noise or distortion.

The Impact of PBL and GI on Scientific Argumentation Skills

The effectiveness of the two instructional models was analyzed using descriptive statistics and the Analysis of Covariance (ANCOVA) to account for initial differences in student ability.

Descriptive Statistics

Dependent Variable: POST_KAI

KELAS	Mean	Std. Deviation	N
PBL	86.4878	5.67945	41
GIL	77.5854	6.43419	41
Total	82.0366	7.51204	82

Figure 3 Descriptive Statistic of SAS test

As shown in Figure 3, the Problem-Based Learning (PBL) group achieved a notably higher mean score (M = 86.4878) compared to the Guided Inquiry (GIL) group (M = 77.5854). To determine if this difference was statistically significant, an ANCOVA was performed.

Table 2 Tests of Between-Subjects Effects

Tests of Between-Subjects Effects	
Sig.	0,000
Partial Eta Squared	0,347

The ANCOVA results in Table 2, confirmed that the instructional model has a significant effect on students' scientific argumentation skills, F = 41.982, Sig. 0.000 (Sig. < 0.05). The Partial Eta Squared value of 0.347 indicates that the instructional model explains approximately 34.7% of the variance in students' argumentation performance, which constitutes a large effect size.

The results of this research indicate that the integration of ChemicalAI into chemistry instruction significantly enhances students' scientific argumentation skills (SAS). However, the statistical analysis reveals that the Problem-Based Learning (PBL) model is more effective than the Guided Inquiry (GI) model. This is evidenced by the significantly higher post-test mean score in the PBL class (86.4878) compared to the GI class (77.5854). These results are largely attributable to the stages of the PBL model. Specifically, during the analysis and evaluate stage, this approach encourage students to cultivate and sustain their scientific arguments through discursive interaction. This process is crucial for synthesizing evidence-based conclusions from teh resolved problems, ensuring that students do not merely find solutions but also justify them rigorous scientific reasoning.

The significant difference in SAS scores, supported by a large effect size (Partial Eta Squared = 0.347), suggests that PBL's instructional flow is better suited for developing scientific argumentation. In the PBL-ChemicalAI framework, learning begins with independent observation, real-world problem regarding chemical reaction rates. This initial "hook" creates a cognitive conflict that necessitates scientific justification. Students are not merely following a procedure; they are required to defend their proposed solutions using empirical data.

Unlike the more linear investigation found in Guided Inquiry, PBL encourages students to engage in high-level discussions, as the PBL model provides more opportunities for students to bridge the gap between their claims and evidence through intensive collaborative debate, a skill that is essential for mastering these high logit reasoning questions.

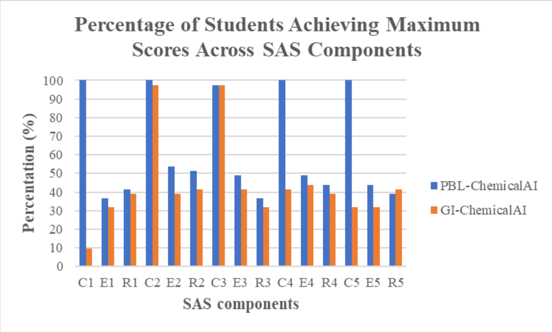

Figure 4 Percentage of Students' Average Score on Each Component: Claim (C), Evidence (E), and Reasoning (R) Components Across Five Tasks (1-5).

To provide a more detailed overview of these findings, Figure 4 illustrates the distribution of students' success in achieving the maximum score for each component of argumentation. The graph groups the tasks into the categories of Claims (C1–C5), Evidence (E1–E5), and Reasoning (R1–R5). The data reveal striking differences in the Claim category; the PBL-ChemicalAI group achieved nearly 100% success on almost all items, whereas the GI-ChemicalAI group demonstrated significantly lower performance, particularly on C1, C4, and C5. Furthermore, although both groups faced greater difficulties in the Evidence and Reasoning stages—reflecting the hierarchy of difficulty identified in the Rasch analysis—the PBL group consistently maintained a higher success rate. This suggests that the PBL framework not only ensures a strong conceptual foundation (Claims) but also provides better support for more complex argumentative elements.

The use of ChemicalAI played a transformative role for both groups, but specifically strengthened the PBL group's argument. By converting experimental digital images into objective quantitative data, ChemicalAI provided the strong evidence needed to construct a valid argument. In the Rasch analysis, Claim (C) items (such as S1C and S3C) are categorized as the easiest for students, as indicated by low logit scores. However, the transition to Evidence (E) and

Reasoning (R) requires objective data to be convincing. ChemicalAI enables students to move beyond subjective observations toward precise analysis. In PBL classes, this objective data forms the backbone of their arguments, making their claims more robust and scientific compared to GI classes, where the focus often remains on the procedural steps of the investigation itself.

The high levels of respondent reliability (0.95) and item reliability (0.96) confirm that the observed differences between the two models are not due to measurement error, but rather reflect genuine differences in student ability. The order of difficulty levels indicates that the claims section is the easiest, followed by evidence, and finally reasoning, which aligns with Sampson's Argument Pattern (SAP).

The fact that students in the PBL group reached higher levels on the Wright Map suggests that the PBL-ChemicalAI integration effectively scaffolded the most challenging aspect of chemistry education: connecting macroscopic observations to submicroscopic reasoning. By solving problems that required the interpretation of AI-generated data, students in the PBL group were forced to articulate the reason and process of reaction rates, thereby excelling in the high-difficulty reasoning items that sat at the top of the item measure scale.

CONCLUSIONS AND SUGGESTIONS

This Research concludes that integrating the ChemicalAI media into chemistry instruction significantly enhances students' Scientific Argumentation Skills (SAS), with the Problem-Based Learning (PBL) model demonstrating a clear superiority over Guided Inquiry (GI). The Rasch Model analysis confirmed the high quality of the measurement instrument, yielding a Person Reliability of 0.95 and an Item Reliability of 0.96. The ANCOVA results further validated this finding, showing a significant difference in SAS performance between the two groups ($F = 41.982$, Sig. 0.000 (Sig. < 0.05)), where the PBL class achieved a substantially higher mean score (86.4878) compared to the GI class (77.5854) .

Furthermore, the Item Measure and Wright Map analysis revealed a distinct hierarchy in students' argumentative abilities based on Sampson's Argument Pattern (SAP). While students found it relatively easy to formulate Claims (C), as indicated by the low logit measures of items like S1C and S3C, they faced the greatest challenge in constructing scientific Reasoning (R), with items S1R, S2R, and S3R identified as the most difficult. The findings indicate that the PBL model when supported by objective data from ChemicalAI media effectively bridges the gap between empirical evidence and complex scientific argumentation in the context of chemical reaction rates.

REFERENCES

[1] UNESCO. (2017). Education for Sustainable Development Goals: Learning Objectives. Paris: UNESCO.

[2] Musfiroh, Y. D., Saadi, P., Syahmani, & Yogo Dwi Prasetyo. (2025). Development of an Sct-Model-Based Chemical Bonding E Magazine To Enhance Students' Critical Thinking Skills and Knowledge Learning Outcomes. *JCER (Journal of Chemistry Education Research)*, *9*(2), 52–61. https://doi.org/10.26740/jcer.v9n2.p52-61

[3] Setyorini, M. D., Rahcmadhaniar, R. N., Naimah, K., & Novita, D. (2024). Validity of Assessment Sheets for Identifying Conceptions and Argumentation Skills in Chemical Equilibrium Materials. *JCER (Journal of Chemistry Education Research)*, *8*(1), 1–8. https://doi.org/10.26740/jcer.v8n1.p1-8

[4] Anisa, Widodo, A., Riandi, & Muslim. (2023). Students' Argumentation in Science Lessons: How effective is Rebuttal Analysis Framework in Representing the Complexity of Classroom Argumentation? *Science & Education*, *32*(3), 669–687. https://doi.org/10.1007/s11191-022-00320-8

[5] Fauziah, A. N. M., Hendratmoko, A. F., Mahdiannur, M. A., Ermawan, M. Z. F., Suwandi, E., & Ratri, S. Y. (2024). The Relationship Between Critical Thinking and Scientific Argumentation in Science Learning. *Jurnal Pendidikan IPA Indonesia*, *13*(2). https://doi.org/10.15294/jpii.v13i2.2585

[6] Putri, T. S., Suyanta, & Rohaeti, E. (2025). Scientific Argumentation in Chemistry Education: A Literature Review of Practices, Challenges, and Solutions. *Tarbiyah: Jurnal Ilmiah Kependidikan*, *14*(1). http://dx.doi.org/10.18592/tarbiyah.v14i1.14666

[7] Zaroh, I., Muntholib, M., & Joharmawan, R. (2022). Implementasi Instrumen Asesmen Argumentasi Ilmiah Materi Laju Reaksi. *Orbital: Jurnal Pendidikan Kimia*, *6*(1), 78–90. https://doi.org/10.19109/ojpk.v6i1.12191

[8] Uçar, S.-Ş., Lopez-Gazpio, I., & Lopez-Gazpio, J. (2025). Evaluating and challenging the reasoning capabilities of generative artificial intelligence for technology-assisted chemistry education. *Education and Information Technologies*, *30*(8), 11463–11482. https://doi.org/10.1007/s10639-024-13295-6

[9] Sari, R. F., Salsa Sabrina Fajar Maulidiah, Liza Nurrahma Dwi Agustin, & Novita, D. (2025). Validity of E-LAPD Based on The Learning Cycle 7-E Model to Improve Critical Thinking Skills Oriented to Multiple Chemical Representations in Reaction Rate Factors Submaterial. *JCER (Journal of Chemistry Education Research)*, *9*(1), 21–28. https://doi.org/10.26740/jcer.v9n1.p21-28

[10] Moju, M., Taylor, L., & Iweuno, B. (2025). Tackling the challenge of chemical representations through sensemaking practices in chemistry education. *Discover Education*, *4*(1), 352. https://doi.org/10.1007/s44217-025-00703-3

[11] Satyaloka, L., & Padmaningrum, R. T. (2025). Systematic Literature Review: Students' Scientific Argumentation Skills in Chemistry Learning. *Indonesian Journal of Chemical Education*, *1*(2), 42–47. https://doi.org/10.21831/ijce.v1i2.81473

[12] Nurhaedah, Suarlin, & Sari, Y. K. (2022). Penerapan Model Pembelajaran Inkuiri Terbimbing Untuk Meningkatkan Keterampilan Berpikir Tingkat Tinggi Siswa Sekolah Dasar. *Pinisi Journal of Education*, *2*(5).

[13] Varadarajan, S., & Ladage, S. (2024). Problem-Based Learning (PBL): A Literature Review of Theory and Practice in Undergraduate Chemistry Laboratories. *Journal of Chemical Education*, *101*(8), 3027–3038. https://doi.org/10.1021/acs.jchemed.3c01335

[14] Okmarisa, H., Lestari, N. A., & Ariani, L. (2025). The Effect of Problem Based Learning Model in Improving Students Argumentation Skills: Systematic Literature Review. *HYDROGEN: Jurnal Kependidikan Kimia*, *13*(1). https://doi.org/10.33394/hjkk.v13i1.14220

[15] De La Puente, M., Torres, J., Troncoso, A. L. B., Meza, Y. Y. H., & Carrascal, J. X. M. (2024). Investigating the use of chatGPT as a tool for enhancing critical thinking and argumentation skills in international relations debates among undergraduate students. *Smart Learning Environments*, *11*(1), 55. https://doi.org/10.1186/s40561-024-00347-0

[16] Anatasya, V., Putra, N., & Triliyansi. (2025). Utilizing AI (Artificial Intelligence) Platforms as Learning Media for MIPA Students at Palangka Raya University. *JCER (Journal of Chemistry Education Research)*, *9*(1), 1–4. https://doi.org/10.26740/jcer.v9n1.p1-4

[17] Harianti, Kadarohman, A., & Anwar, S. (2025). Pre-Service Chemistry Teachers' Knowledge, Usage and Perceptions of Artificial Intelligence in Education. *JCER (Journal of Chemistry Education Research)*, *9*(1), 5–12. https://doi.org/10.26740/jcer.v9n1.p5-12

[18] Sampson, V., & Walker, J. P. (2012). Argument-Driven Inquiry as a Way to Help Undergraduate Students Write to Learn by Learning to Write in Chemistry. *International Journal of Science Education*, *34*(10), 1443–1485. https://doi.org/10.1080/09500693.2012.667581

[19] Neva Lionitha Ibrahim. (2025). Analisis Literatur Penggunaan Model Rasch untuk

Validasi Instrumen Asesmen Pendidikan: Tren, Temuan, dan Implikasi. *Lencana: Jurnal Inovasi Ilmu Pendidikan*, *3*(2), 46–60. https://doi.org/10.55606/lencana.v3i2.5012

[20] Hasanah, S. M., Rahayu, S., Sulistina, O., & Alsulami, N. M. (2025). Creating and Validating a Chemical Literacy Instrument Aligned Sustainability Contexts: Construct and Rasch Measurement Analysis. *Jurnal Pendidikan Sains Indonesia*, *13*(2), 408–425. https://doi.org/10.24815/jpsi.v13i2.44678

[21] Kurniasih, N., Rahmansyah, S., Nuriman, H., Roza, P., Nurhayati, I. K., & Hidayat, E. F. (2025). Assessing multimodal reading comprehension in STEM education: A Rasch model approach. *Language Testing in Asia*, *15*(1), 74. https://doi.org/10.1186/s40468-025-00373-w

[22] Setyorini, A. D., Yamtinah, S., Mahardiani, L., & Saputro, S. (2021). A Rasch Analysis of Item Quality of the Chemical Literacy Assessment for Investigating Student's Chemical Literacy on Chemical Rate Concepts. *European Journal of Educational Research*, *volume–10–2021*(volume–10–issue–4–october–2021), 1769–1779. https://doi.org/10.12973/eu-jer.10.4.1769

[23] Dong, Y., Xu, W., Huang, J., & Yann, K. (2025). Validating and refining a multi-dimensional scale for measuring AI literacy in education using the Rasch Model. *Humanities and Social Sciences Communications*, *12*(1), 1317. https://doi.org/10.1057/s41599-025-05670-6