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Student's performance dataset on multidimensional 21st-century thinking skills in physics ability assessment

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Assessing students' 21st-century thinking skills is essential to meet the demands of modern education, support academic achievement, and align with evolving educational standards. This paper presents an open dataset on educational measurement of students' performance in critical and creative thinking, within the theoretical framework of assessing physics ability as a multidimensional construct. Our data were collected using researcher-developed instruments comprising 12 essay items. Some experts in educational measurement and physics education reviewed the instruments. A total of 330 senior high school students from three schools in Indonesia participated in the assessment. After attempting the test, all participants were given a structured questionnaire to evaluate the practicality and usefulness of the developed instruments, which yielded overall positive responses. This dataset supports the development of more effective assessment models for 21st-century competencies. It offers valuable insights for educators, researchers, and policymakers to inform curriculum design and policy development aligned with 21st-century learning objectives.

Background & Summary

Assessing students' performance in 21st-century thinking skills is vital for preparing them to meet the demands of the modern world, enhancing their academic success, and ensuring effective learning strategies and alignment with educational standards[1,2]. Physics education holds a crucial role in integrating and assessing 21st-century skills. We must design compelling learning experiences, utilize appropriate assessment tools, engage in continuous professional development, and create supportive learning environments to prepare students for the demands of the modern world[3]. Therefore, a physics education study focusing on assessments can drive our learning forward by providing feedback, motivating students, and helping them develop critical thinking and problem-solving skills[4,5]. Assessments also help teachers identify learning gaps and adjust their teaching strategies accordingly[6]. Effective assessment practices are crucial to ensure students acquire these skills.

Physics is a subject that holds a significant position in promoting critical thinking and essential life skills[7]. By integrating interactive teaching methods, emphasizing problem-solving skills, and fostering experimental abilities, physics education prepares students to navigate and succeed in a rapidly changing world. The balance between conceptual understanding and critical thinking is crucial for maximizing the benefits of physics education[8–10]. Physics education is crucial in fostering creative thinking and essential life skills among students. This is particularly important in preparing future generations to tackle complex and challenging problems with innovative solutions[11,12]. One might argue that the available assessments in the field for measuring 21st-century skills still need improvement. Therefore, we developed an assessment of physics ability that integrates multidimensional 21st-century thinking skills. In the end stage, we assess students' performance through an assessment that has been accurately and systematically developed.

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Our developed instruments offer strength within the theoretical framework of multidimensional thinking skills. We developed a critical and creative thinking skills instrument in physics to address the lack of assessment tools for students' skills, particularly in Indonesia. We also utilize the essay test because it more effectively evaluates students' ability to organize thoughts, develop arguments, and demonstrate critical thinking skills. They require students to produce and structure their responses, which can better assess their understanding and analytical abilities[13,14]. Essay tests enable students to delve more deeply into topics and demonstrate a comprehensive knowledge of the subject matter. This is particularly important in fields that value analytical writing and detailed explanation[14]. While multiple-choice tests are efficient and can quickly cover a wide range of topics, essay tests offer significant advantages for assessing higher-order cognitive skills and writing proficiency[15,16].

Sharing datasets of 21st-century thinking skills is vital for improving educational practices, supporting research and innovation, meeting workforce demands, promoting open science, and overcoming barriers to data sharing[17–22]. Teachers, researchers, and educational practitioners can utilize this data to enrich the assessment model for measuring 21st-century skills. Policymakers and curriculum designers can adopt this data to align relevant policies and curricula to 21st-century needs. By making these datasets available, we can foster a more collaborative and practical approach to developing the skills necessary for success in the 21st century. This data-sharing article presents physics as part of critical and creative thinking, a 21st-century skill. We also present the response of high school students to capture the usefulness and practicality of the test instruments. The dataset, available in raw, filtered, and analyzed formats, offers valuable insights into the assessment model in 21st-century skill thinking. This dataset intends to develop an assessment model for physics ability in 21st-century thinking skills.

To the best of our knowledge, there is still a limited number of similar datasets, as reported in this paper. The value of our data is relevant to the needs of 21st-century learning that we have encountered in recent days. The dataset could inspire future researchers to capture the portrait of students' competence in 21st-century learning in Indonesia, providing empirical evidence that enriches the broader discourse of educational innovation. Furthermore, this dataset may serve as a valuable baseline for longitudinal studies, enabling scholars to track changes in students' competence development over time and to evaluate the impact of different instructional approaches. Policymakers could also benefit from our data to plan strategic programs that enhance the effectiveness of physics instruction and meet the call for learning innovation. In addition, practitioners and educators may use the insights drawn from the dataset to refine teaching practices, design contextually relevant interventions, and align classroom strategies with the demands of global competencies. Ultimately, the contribution of this dataset extends beyond research purposes, providing a foundation for evidence-based decision-making to shape the future of physics education and foster students' readiness to face the challenges of the modern world.

Methods

Ethics Statement. The research conducted in this study was reviewed and approved by the Ethics Committee at the Institute of Research and Community Service of Universitas Negeri Yogyakarta, under the ethical approval number T/27/UN34.9/KP.06.07/2024, dated October 19, 2024. All necessary permissions were obtained in a systematic and ethical manner, as outlined in the research project proposal. The research aims to publish an open dataset of students' responses on physics and 21st-century thinking skills, along with questionnaires that have undergone a thorough review. School heads, physics teachers, and students (with parental consent) coordinated with the researchers regarding the study description, including the practical objectives and methods of the research project, and provided their consent to participate in the test. They agreed that their data would be collected and consented to the use of the demographic and physics ability data to the extent necessary for the research project. Students' and schools' privacy was securely protected by fully anonymizing their specific identities during test administrations and in the records reported in this dataset. We obtained consent from 330 participants to share anonymized data openly for research and education, and we ensured confidentiality through approved anonymization and data-handling procedures.

Participants and Context. Participants in this study are 11th-grade students in a densely populated city in Central Indonesia, attending three senior high schools that have studied the test material. The testing was conducted to assess students' physics performance, which integrated 21st-century thinking skills. The test subjects consisted of 330 students, comprising 136 males and 194 females as shown in Table 2. While School C is larger than Schools A and B (Tables 1), the current policy in the Indonesian national educational system requires schools to implement a zoning-based enrollment system to distribute students more evenly among schools. Consequently, all schools would have equal student input, even though they may differ in status, teacher quality, size, facilities, and location.

Each student responded to the usefulness and practicality of the instrument after the test to capture their opinion. The usefulness questionnaire consists of three items, and the practicality questionnaire comprises seven items. Generally, they respond positively to the physics ability instrument in 21st-century thinking skills (see Table 3).

Data Collection. Data were collected through test measurements in three schools. There are five main indicators of physics ability in 21st-century thinking skills as summarized in Table 4, including critical and creative thinking, as well as analytical, evaluative, flexible, original, and fluent thinking. The indicators are relevant to high-order thinking skills (HOTS) in revised Bloom's taxonomy, such as analyze, evaluate, and create levels[23].

To measure students' performance in physics, there are three main topics: fluid mechanics, thermodynamics, and waves (as shown in Table 5). Each topic is related to the main indicator of 21st-century thinking skills. The initial design comprises fifteen test items, and each main indicator is represented by three items. For example,

No	School	Participants Total	Cohort Total
1	School A	62	3
2	School B	35	3
3	School C	233	7
Total		**330**	**13**

Table 1. The summary of the school, cohort, and participants.

	School A		School B		School C		Total	
Gender	Freq. (N)	Pct. (%)	Freq. (N)	Pct. (%)	Freq. (N)	Pct. (%)	Freq. (N)	Pct. (%)
Male	**33**	**53.23%**	**19**	**54.29%**	84	36.05%	136	41.21%
Female	29	46.77%	16	45.71%	**149**	**63.95%**	**194**	**58.79%**

Table 2. The demographics of participants and their responses to the test instrument by gender.

Students' Response	School A		School B		School C		Total	
	Freq. (N)	Pct. (%)	Freq. (N)	Pct. (%)	Freq. (N)	Pct. (%)	Freq. (N)	Pct. (%)
Usefulness (3 Items)								
1. I gained new knowledge about physics concepts after taking the test								
Positive	**47**	**75.81%**	**32**	**91.43%**	**206**	**88.41%**	**285**	**86.36%**
Negative	15	24.19%	3	8.57%	27	11.59%	45	13.64%
2. The test led me to learn more about physics material								
Positive	**55**	**88.71%**	**35**	**100.00%**	**213**	**91.42%**	**303**	**91.82%**
Negative	7	11.29%	0	0.00%	20	8.58%	27	8.18%
3. After taking the test, I prefer physics subjects								
Positive	**41**	**66.13%**	**19**	**54.29%**	110	47.21%	**170**	**51.52%**
Negative	21	33.87%	16	45.71%	**123**	**52.79%**	160	48.48%
Practicality (7 Items)								
1. The manual for testing is clear								
Positive	**50**	**80.65%**	**24**	**68.57%**	**198**	**84.98%**	**272**	**82.42%**
Negative	12	19.35%	11	31.43%	35	15.02%	58	17.58%
2. In general, the meaning of the sentence in the test is easy to understand								
Positive	**41**	**66.13%**	**19**	**54.29%**	**148**	**63.52%**	**208**	**63.03%**
Negative	21	33.87%	16	45.71%	85	36.48%	122	36.97%
3. Easy-to-read test item statements								
Positive	**53**	**85.48%**	**32**	**91.43%**	**204**	**87.55%**	**289**	**87.58%**
Negative	9	14.52%	3	8.57%	29	12.45%	41	12.42%
4. The figures in the test are easy to understand								
Positive	**51**	**82.26%**	**30**	**85.71%**	**204**	**87.55%**	**285**	**86.36%**
Negative	11	17.74%	5	14.29%	29	12.45%	45	13.64%
5. Graphs in tests are easy to understand								
Positive	**47**	**75.81%**	**25**	**71.43%**	**202**	**86.70%**	**274**	**83.03%**
Negative	15	24.19%	10	28.57%	31	13.30%	56	16.97%
6. The test completion duration is sufficient for all question items								
Positive	**47**	**75.81%**	**21**	**60.00%**	**157**	**67.38%**	**225**	**68.18%**
Negative	15	24.19%	14	40.00%	76	32.62%	105	31.82%
7. Physics equations in tests are easy to understand								
Positive	**34**	**54.84%**	14	40.00%	**139**	**59.66%**	**187**	**56.67%**
Negative	28	45.16%	**21**	**60.00%**	94	40.34%	143	43.33%

Table 3. Students' response to physics ability in the 21st-century thinking skill test.

the C2 item is the second item of producing flexibility. The learning objective refers to the national curriculum for senior high school physics in Indonesia. Each learning objective has specific item indicators to measure the extent to which the item integrates 21st-century thinking skills. Before testing, seven experts reviewed the initial design to assess content validity.

Indicators	Item Indicators
Analytical Thinking	Given questions, students can analyze the solution to the problem correctly (A)
Evaluation Thinking	Given a question, students can determine the truth of a question or statement correctly (B)
Producing Flexibility	Given the question, students can solve problems in more than one way (C)
Producing Originality	Given questions, learners can find unusual ways to solve problems correctly (D)
Producing Fluncy	Given questions, students can answer in detail to solve problems correctly (E)

Table 4. Indicators and Item Indicators of Physics Ability Assessment.

Topic	Learning Objective	Specific Item Indicators	Items	Item Form
Fluid Mechanic	Analyze the laws of fluid mechanics to solve problems of daily life	Identifying the effect of fluids on string tension (A)	A1	Essay
		Assessing changes in the volume of liquids when ice cubes melt (B)	B1	Essay
		Performing mass determination based on the graph in several ways (C)	C1	Essay
		Producing an unusual way of determining the pressure of a liquid substance (D)	D1	Essay
		Mentioning the steps in measuring irregular objects using fluids (E)	E1	Essay
Thermodynamic	Analyze the effect of heat, heat transfer, and changes in the state of ideal gases by applying the law of thermodynamics	Identifying thermodynamic processes based on graphs (A)	A2	Essay
		Assessing temperature changes based on the specific heat capacity that a substance has (B)	B2	Essay
		Performing the determination of the work in thermodynamics based on graphs in several ways (C)	C2	Essay
		Producing an unusual way of determining the work in the thermodynamic process (D)	D2	Essay
		Mentioning in detail the things considered in underground insulated storage based on the concept of heat transfer (E)	E2	Essay
Wave	Analyze the relationship between force and vibration in everyday life	Identifying the effect of string tension and rope tightness on pulse velocity (A)	A3	Essay
		Assessing the effect of frequency changes on wavespeed, wavelength, and amplitude (B)	B3	Essay
		Calculating velocity based on wave equations in several ways (C)	C3	Essay
		Producing an unusual way of determining the wavespeed, wavefrequency, and maximum transverse speed of particles when the amplitude is changed (D)	D3	Essay
		Describing in detail the steps to generate interference patterns in waves (E)	E3	Essay

Table 5. Topic, Learning Objective, and Specific Item Indicators of Assessment.

Data Records

The student's performance dataset on physics ability in 21st-century thinking skills is publicly available on the Mendeley Data Repository[24] at https://data.mendeley.com/datasets/fbw5r48r73/1. Student's performance data is open access and licensed under Creative Commons Attribution 4.0 International (CC BY 4.0). All the data is structured as a single tabular file (21st Century Thinking Skills.xlsx) for ease of use. There are two sheets in the XLSX file where the primary data is stored in the first sheet ("PHYS21STTHINKING"), and the second sheet ("Codes") contains further details of columns (variables/ features) and their corresponding values or categories. The PHYS21STTHINKING refers to Physics in 21st-Century Thinking skills. Students' identities have been anonymized using a code system described by a letter and four unique numbers. Each letter indicates the students' schools (A, B, or C). The first number then pertains to their cohort within school, and the last three numbers denote the alphabetical order of the students' names within the cohort. School documents recorded data on the cohort, gender, and curricula. The student's performance in physics, as measured by 21st-century thinking skills, was assessed through a paper test that included two 21st-century thinking skills: critical and creative thinking. The PHYSACRI refers to Physics Ability in Critical Thinking, and the PHYSACRE refers to Physics Ability in Creative Thinking. Furthermore, the students' responses regarding the usefulness and practicality of the instrument test were recorded using a questionnaire.

Technical Validation

Seven experts in educational measurement, physics education, and physics reviewed the test instrument to assess students' performance in 21st-century thinking skills as shown in Table 6. Expert judgment was used to ensure the instrument's quality before testing.

The expert-judgment analysis was conducted using Aiken's method to assess the instrument's content validity. Item content-relevance is an essential consideration for researchers when developing scales used to measure

No	Expert	Specialization
1	Expert 1	Educational Measurement Physics Education
2	Expert 2	Educational Measurement Physics Education
3	Expert 3	Physics
4	Expert 4	Physics Education
5	Expert 5	Educational Measurement Physics Education
6	Expert 6	Physics Education
7	Expert 7	Physics Education

Table 6. Expert in Content Validation.

	Rater Scores									
Items	1	2	3	4	5	6	7	Aiken V	V-table	Notes
A1	3	4	4	4	3	4	4	0.905	0.76	Valid
A2	3	4	4	4	4	4	4	0.952	0.76	Valid
A3	3	2	2	2	4	4	4	0.667	0.76	Invalid
B1	4	4	4	4	4	4	4	1.000	0.76	Valid
B2	4	4	4	4	3	4	4	0.952	0.76	Valid
B3	4	4	4	4	4	4	4	1.000	0.76	Valid
C1	3	3	2	2	4	4	4	0.714	0.76	Invalid
C2	4	4	4	4	4	4	4	1.000	0.76	Valid
C3	4	4	4	4	4	4	4	1.000	0.76	Valid
D1	3	4	4	4	4	4	4	0.952	0.76	Valid
D2	2	3	3	2	4	4	4	0.714	0.76	Invalid
D3	4	4	4	4	4	4	4	1.000	0.76	Valid
E1	4	4	4	4	4	4	4	1.000	0.76	Valid
E2	4	4	4	4	4	4	4	1.000	0.76	Valid
E3	4	4	4	4	4	4	4	1.000	0.76	Valid
Average								**0.924**	**0.76**	**Valid**

Table 7. Results of the Aiken Test validity analysis.

psychological constructs[25]. Aiken's validity is rated with the highest score of 4 and the lowest score of 1, with the criteria of 4 Very Good, 3 Good, 2 Poor, and 1 Very Poor. All experts review all of the instrument items.

The Aiken test validity analysis results are used to determine whether an item is valid or invalid by comparing Aiken V with the V-table. The results of Aiken's validation showed three invalid items out of fifteen as shown in Table 7. The invalid items are A3, C1, and D2, so the test uses 12 items. The test instrument has good content validity, with Aiken's V being 0.924. Therefore, this dataset comprises twelve items to assess students' performance in 21st-century thinking skills, excluding items A3, C1, and D2.

Usage Notes

- The data presented is valuable and beneficial to physics education to assess students' performance in 21st-century thinking skills in Indonesia, especially for critical and creative thinking skills.
- Teachers, researchers, and educational practitioners can use this data to enrich the assessment model for measuring 21st-century skills. The psychometric properties can be further examined by analyzing the data, such as through Confirmatory Factor Analysis (CFA), Classical Test Theory (CTT), and Multidimensional Item Response Theory (MIRT).
- Policymakers and curriculum designers can also adopt this data to align relevant policies and curricula to 21st-century needs. Especially, how to integrate the 21st-century thinking skills into the physics curriculum in senior high school.
- By making these datasets publicly accessible, we seek to promote a more collaborative, inquiry-driven, and practice-oriented approach to learning. Open data availability allows students, educators, and researchers to engage directly with authentic datasets, thereby bridging the gap between theoretical knowledge and empirical application. Such engagement encourages the co-construction of knowledge, fosters interdisciplinary collaboration, and enhances the development of critical 21st-century competencies—particularly critical and creative thinking skills essential for participation in contemporary knowledge societies.
- The dataset does not encompass all dimensions of 21st-century thinking skills, as specific higher-order competencies—such as computational and metacognitive thinking skills—were beyond the scope of measurement in the present study.

Data availability

The student's performance dataset on physics ability in 21st-century thinking skills is openly available on the Mendeley Data Repository at https://data.mendeley.com/datasets/fbw5r48r73/1. Student's performance data is open access and licensed under Creative Commons Attribution 4.0 International (CC BY 4.0).

Code availability

No custom code was used.

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W.: Conceptualization, Software, Formal analysis, Investigation, Data curation, Visualization, Writing - Original Draft, Writing - Review & Editing. B.S., R., A.H., E.F.L.S., E.I., H.R., P.H.S.: Data curation, Validation, Writing - Review & Editing. All authors reviewed and approved the published manuscript.

Competing interests

The authors declare no competing interests.

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