

Evaluating the Quality of STEM-PjBL Learning Materials on Stoichiometry Supported by a Simple Photometer: An Aiken's Index Approach

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Abstract. The development of STEM-project-based learning (STEM-PjBL) materials demands rigorous validation to ensure their quality, effectiveness, and relevance to learning objectives, particularly in complex chemistry topics such as stoichiometry. However, many existing tools lack rigorous validation, potentially undermining the credibility of both research outcomes and educational practices. This study aims to evaluate the quality of STEM-PjBL learning materials on stoichiometry supported by a simple photometer, by assessing the content validity of various instructional and assessment instruments using Aiken's Index. A quantitative document analysis approach was employed, with validation conducted through a focus group discussion (FGD) involving seven experts: four chemistry education lecturers from Sebelas Maret University and Padang State University, and three experienced high school chemistry teachers from Surakarta. The instruments evaluated included a teaching module, student worksheet, STEM-PjBL implementation and sustainability literacy questionnaire, sustainability literacy pre-test and post-test, observation sheet for student performance during practicum, water filtration project scoring rubrics, and a cognitive pre-test and post-test on stoichiometry. Expert judgments focused on the clarity, relevance, and alignment of each item with intended learning indicators. The Aiken's V coefficient was used to measure inter-rater agreement, with a threshold of ≥ 0.76 indicating acceptable content validity. All instruments met the criteria for high content validity. These findings confirm that the developed STEM-PjBL materials and assessment tools are valid and suitable for classroom implementation, offering strong support for enhancing students' conceptual understanding, performance skills, and sustainability literacy in chemistry education.

Keywords: Aiken index, content validity, sustainability literacy, simple photometer, STEM-project-based learning

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Introduction

Rapid technological and scientific advances have led humans to various environmental problems, such as climate change, reduced biodiversity, and declining ecological quality (Gunansyah et al., 2022). Development that does not consider sustainability contributes to this condition, endangering human life and other creatures on

earth (Evans, 2016; Zhang et al., 2024). Education has a crucial role in supporting sustainable development because education can help a generation that is more aware and concerned about the environment take concrete actions to preserve life (Kopnina & Meijers, 2014; Mahlaole, 2025; Tafese & Kopp, 2025). Unfortunately, students' awareness of environmental issues, or what is commonly called sustainability literacy, is still at the middle level. According to Kieu et al. (2016), students' sustainability literacy skills are still in the middle category (Adam et al., 2021). That way, education for sustainable development (ESD) is present in education as one of the efforts to build awareness of sustainable development for students. According to the United Nations, ESD is a learning approach based on the principles of sustainable development (Ekantini & Wilujeng, 2018).

One of the materials that can be associated with sustainability literacy is stoichiometry. Stoichiometry is very important for students to understand the qualitative and quantitative aspects of a chemical reaction, so it becomes the basis for solving many problems in chemistry (Giunta, 2016; Chonkaew et al., 2016; Chonkaew et al., 2019). However, what happens in Indonesia in the learning process of stoichiometry is that most educators focus more on calculations only; students are not invited to think more critically about the application of the concept of stoichiometry in their lives, especially in efforts for sustainable development. Based on this, in learning chemistry on the topic of stoichiometry, a learning model is needed that supports students to build their knowledge of the concepts learned and provides opportunities for students to use ideas understood in daily life.

STEM-project-based learning (STEM-PjBL) can solve these problems; through STEM-PjBL, students develop the potential to directly interact with problems in the real world, one of which is environmental issues. STEM-PjBL is one of the learning approaches where students can see concepts, principles, science, technology, and mathematics integrated into developing products, processes and systems that can be used in daily life (Oktavia & Sutoyo, 2021; Imaduddin et al., 2022). The STEM-PjBL model can answer the challenges of 21st-century learning that require high-level thinking skills and contextual learning supported by technology (Shidiq et al., 2022).

The development of technology, in tandem with the advancement of science, has given birth to technology-based learning media that are applied to help the teaching and learning process, for example, spectrophotometers. A spectrophotometer is an instrument used to determine the concentration of a sample based on the ratio of the colour intensity of the solution to the visible light (Taufik, 2020). Introducing the spectrophotometer instrument in education, especially in practicum activities, can help facilitate the learning process, especially for chemistry subjects (Shidiq et al., 2021b). However, the existence of spectrophotometers as a medium of learning chemistry is still limited. This is due to the relatively high price of the instrument, which means that not all schools can access it to support practicum activities (Putra & Yulkifli, 2019). To answer these problems, a simple photometer with a light emitting diode-red, green, blue (LED RGB) is essential.

Based on literature studies, no research has applied STEM-PjBL to stoichiometry materials with the help of a simple photometer at the high school level. This study's novelty is applying a simple photometer with LED RGB on stoichiometric materials using the STEM-PjBL model to measure literacy, sustainability, and student learning outcomes. The learning process is an essential component of learning assessments. Assessment in learning is a process to obtain a certain amount of information about the development of students during learning activities, as material for decision-making by teachers to know and improve the learning process and outcomes of students through an instrument (Imania & Bariah, 2019). Learning assessment instruments can be in the form of tests or non-tests. Assessment instruments are said to meet the criteria as good measuring tools, which can be seen through their validity. This study will discuss the results of the validity of the instrument's content that will be used to measure the literacy ability of sustainability and

students' learning outcomes on stoichiometric material, assisted by a simple photometer with an LED RGB.

Methods

This study analyses the content's validity based on the Aiken index of the instrument to be used to collect research data. The research began with the development of test and non-test instruments that aimed to measure the literacy ability of sustainability and learning outcomes of STEM-PjBL students with the help of a simple photometer with an LED RGB. Sustainability literacy includes 8 indicators, according to Ozdemir (2021), including ecological principles and processes; natural resources, human use and environmental damage; consumption patterns; household; participation; Concerns; social responsibility; and the locus of control. Meanwhile, the STEM-PjBL syntax uses the stages of the engineering design process (EDP) proposed by Capraro & Jones (2013), including identifying problems and constraints, researching the issue, ideating (developing a possible solution), analysing the idea (selecting a promising solution); building, testing, and refining; communicating and reflecting (Shidiq et al., 2022). There are 7 instruments developed in this study, summarised in Table 1.

Table 1. Types and number of items for each instrument in the study

No	Instrument Type	Number of Item
1.	Teaching module	21
2.	Student worksheet	18
3.	STEM-PjBL implementation and sustainability literacy questionnaire	27
4.	Sustainability literacy pre-test and post-Test	16
5.	Observation of student performance in practicum	6
6.	Water filtration project scoring rubrics	20
7.	Pre-test this Post-test cognitive	10

The instrument that has been developed requires a content validity analysis to improve the test item and prove that the instrument can measure what should be measured (Ikhsanudin & Subali, 2018). In this study, the instrument was validated by 7 expert validators, including 4 university lecturers and 3 chemistry teachers, through discussions in focus group discussions (FGD). The researcher provided a validation sheet containing the grid and instrument items, scoring rubrics, and input and suggestions columns. The expected input and suggestions include the suitability of the instrument made with the indicators, the clarity of the presentation of sentences in the question, and the use of language. The existence of input and suggestions from validators can be an improvement for researchers. Content validation is carried out by giving a score of 1 – 4 to each item, namely a score of 1 with irrelevant (IR), a score of 2 with less relevant (LR), a score of 3 with quite relevant (QR), and a score of 4 with relevant (R). The content validity test uses Aiken's validity theory (Aiken's V), and the scoring results are calculated using the Aiken formula with the following formula:

$$V = \frac{\sum S}{n(C - 1)} \quad (1)$$

$$S = R - Lo \quad (2)$$

Remark:

V: Index Aiken

S: The score given by the assessor minus the lowest score in the category
R: The score given by the assessor
T: Lowest rating score (1)
C: Highest scoring score (4)
n: Number of validators (assessors)

Results and Discussion

Validity, this means how far the accuracy and precision of a test instrument are in performing the measurement function. A test instrument can have high validity if it performs the measurement function correctly or produces measurement results. One of the concepts of test validity is content validity, where content validity shows the extent to which the question items in an instrument represent the overall indicators or material being tested (Utami et al., 2024). The discussion of this study is focused on the analysis of content validity using the Aiken index by 7 expert validators. The validity of a question item can be said to be good, according to Aiken, if seven expert validators with four score categories get an Aiken index greater than or equal to 0.76 (Aiken, 1985).

The Aiken index expresses the expert validator's agreement index regarding the suitability of an item with the indicators that need to be measured with the item. The Aiken validity index has 3 criteria: if the expert validator's assessment has a value below 0.4, it is declared low validity; if the value is between 0.4 and 0.8, it is declared medium validity; and if it is above 0.8, it is declared high validity (Aiken, 1985). An Aiken index value close to 1 means the instrument is better because it is more relevant to the indicator (Utami et al., 2024). In this study, there are 8 instruments, with the results of each Aiken calculation as follows.

Teaching module instrument

The teaching module in the research uses the STEM-PjBL model with stages of the EDP. Teaching modules are a learning design presented thoroughly and systematically by the existing curriculum; the application of planned teaching modules helps students achieve the competency standards that have been set (Salsabilla et al., 2023). In this study, the teaching module instrument contains 3 aspects that are validated, namely the element of format (items 1-5), language (items 6-12), and content (items 13-21), where, when added, 21 items are assessed. The results of validation are presented in Table 2.

Based on the results of the calculation of the Aiken index in Table 2, the teaching module instrument produces relevant and irrelevant values limited by the standard value V of 0.76, where there are 20 relevant items and 1 irrelevant item. Even so, the overall average result of the V value is 0.96, so it can be categorised at a high level of validity (Ahmad et al., 2024). One irrelevant item is the content aspect with item number 15 in the form of the suitability of learning objectives, indicators, and basic competencies. The results of the analysis of the Aiken index on 21 items of the teaching module instrument show that one item is declared irrelevant, namely item number 15. The irrelevant value in item number 15 means that the module's learning objectives, indicators, and basic competencies still do not have the right relationship, so improvement is needed. Improvement of teaching module instruments needs to consider comments from expert validators. The expert validators' comments on the teaching module instrument can be seen in Table 3.

Table 2. Results of the analysis of the Aiken index teaching module instrument

Aspects	Item Number	Standard Value V	Value V	Conclusion
Format	1	0.76	0.86	Relevant
	2	0.76	1.00	Relevant
	3	0.76	1.00	Relevant
	4	0.76	1.00	Relevant
	5	0.76	1.00	Relevant
Language	6	0.76	1.00	Relevant
	7	0.76	1.00	Relevant
	8	0.76	1.00	Relevant
	9	0.76	1.00	Relevant
	10	0.76	1.00	Relevant
	11	0.76	1.00	Relevant
	12	0.76	1.00	Relevant
	13	0.76	0.86	Relevant
	14	0.76	1.00	Relevant
	15	0.76	0.71	Irrelevant
Fill	16	0.76	1.00	Relevant
	17	0.76	0.86	Relevant
	18	0.76	1.00	Relevant
	19	0.76	1.00	Relevant
	20	0.76	0.86	Relevant
	21	0.76	1.00	Relevant

Table 3. Expert validator's comments on the teaching module instrument

Validator Comments	Responses
Please adjust the completeness of the teaching module to the merdeka curriculum.	The teaching module is improved by adjusting the merdeka curriculum.
The teaching module's components are detailed per the applicable curriculum.	The components of the teaching module that are not equipped are based on the merdeka curriculum.
Re-examine the time allocation.	The time allocation for each learning stage is adjusted to the needs of teaching and learning so that it is neither too long nor too fast.
The suitability of learning objectives, indicators, and basic competencies, especially sustainability literacy indicators, can be clarified.	An explanation of sustainability literacy indicators was added at each stage of learning.

The revisions made to the teaching module following expert feedback are consistent with previous research emphasizing the importance of content alignment, clarity, and integration of STEM principles in instructional design. Studies by Pertiwi et al. (2022) and Adha et al. (2021) highlight that STEM-integrated modules must not only follow the structure of national curricula but also explicitly support higher-order thinking and scientific literacy through clear learning trajectories. The incorporation of sustainability literacy indicators and alignment with the merdeka curriculum in this study reflect similar efforts

to ensure conceptual coherence and contextual relevance. Furthermore, prior research has shown that modules designed with careful attention to format, language, and content validity tend to improve student engagement and cognitive development, particularly in complex topics such as chemistry. These findings reinforce the necessity of rigorous validation in developing high-quality teaching materials that are both pedagogically sound and practically applicable in STEM-PjBL contexts (Adha et al., 2023; Pertiwi et al., 2024).

Student worksheet instrument

Student worksheet is one of the learning tools in the form of sheets that can contain material summaries and assignment instructions for students in learning activities (Kholifahtus & Wardoyo, 2021). Student worksheet shows students learning activities and how the teaching process will occur in specific subjects and materials (Kibar & Ayas, 2010). The student worksheet instrument used in this study uses the STEM-PjBL model with the EDP, which is adjusted to 3 types according to the ability of students based on the results of the cognitive pre-test, namely student worksheet proficient (items 1-6), moderately proficient (items 7-12), and needs guidance (Items 13-18).

Table 4. Analysis results of the Aiken index of student worksheet instrument

Types of student worksheet	Item Number	Standard Value V	Value V	Conclusion
Proficient	1	0.76	1.00	Relevant
	2	0.76	1.00	Relevant
	3	0.76	0.86	Relevant
	4	0.76	1.00	Relevant
	5	0.76	0.86	Relevant
	6	0.76	0.86	Relevant
Moderately proficient	7	0.76	1.00	Relevant
	8	0.76	1.00	Relevant
	9	0.76	0.86	Relevant
	10	0.76	1.00	Relevant
	11	0.76	1.00	Relevant
	12	0.76	1.00	Relevant
Needs guidance	13	0.76	0.86	Relevant
	14	0.76	1.00	Relevant
	15	0.76	0.86	Relevant
	16	0.76	1.00	Relevant
	17	0.76	1.00	Relevant
	18	0.76	1.00	Relevant

Based on the results of the calculation of the Aiken index in Table 4, the student worksheet instrument produces relevant and irrelevant values, which are limited to the standard value V of 0.76; the student worksheet instrument produces 18 relevant items. The average result of the overall V value is 0.95, so it can be categorised as a high level of validity (Utami et al., 2024). The results of the analysis of the Aiken index on 18 items used for the student worksheet instrument show that all items are relevant, meaning that the student worksheet, whether it has the categories of advanced, quite proficient, or needs guidance, is based on the existing materials and indicators. Therefore, the student worksheet instrument can be used for the next stage, namely data collection, without any improvement. The expert validators' comments on the student worksheet instrument can be seen in Table 5.

Table 5. Expert validator's comments on student worksheet instrument

Validator Comments	Responses
There is a use of sentences that are still ambiguous.	The student worksheet is re-examined, and if ambiguous sentences are found, the sentence structure is changed so that the instructions are clear.
Suggestions to replace 'causal conclusions' with 'causal factors' or 'root causes'.	'Causal conclusion' replaced with 'causal factors'
The boundary between student worksheet advanced, quite proficient, and need guidance can be clarified because it still looks the same.	The completeness of the information at each stage of learning is clarified so that the distribution of student worksheet is visible.

The expert validation of the student worksheet highlights the importance of linguistic clarity, conceptual accuracy, and differentiation in instructional design. Revisions addressing ambiguous sentence structures and inappropriate terminology such as replacing “causal conclusions” with “causal factors” are crucial to ensuring that students clearly understand the learning tasks and can engage meaningfully with the content. Additionally, clarifying the distinctions among performance levels (advanced, quite proficient, need guidance) helps provide scaffolding aligned with student competencies, which is vital in student-centered and inquiry-based learning. These revisions are in line with findings by Ekantini & Wilujeng (2018), who emphasized that well-structured worksheets should not only facilitate scientific literacy but also support environmental and contextual understanding. Similarly, the use of clear, culturally responsive, and pedagogically grounded design elements as noted by Alexon & Handayani (2024) can enhance the usability and instructional impact of worksheets. Overall, the validated student worksheet demonstrates improved coherence and pedagogical relevance, reinforcing its role as a supportive tool within the STEM-PjBL framework for fostering both conceptual understanding and learner autonomy (Ekantini & Wilujeng, 2018; Alexon & Handayani, 2024).

Sustainability literacy

The measurement of students' literacy ability uses indicators according to Ozdemir (2021), including 8 indicators detailed in Table 6. Based on the indicators mentioned as the basis for making the instrument, the following are instruments to measure sustainability literacy ability. The sustainability literacy questionnaire instrument is a research data collection tool that involves writing statements and questions and distributing them to respondents (Wicaksana, 2020).

In this study, the questionnaire developed was a learning questionnaire using the Likert scale method. The Likert scale is a scale that measures the attitudes, opinions, and perceptions of a person or a group of people. Questionnaire methods that use the Likert scale can produce accurate and tested data (Santika et al., 2023). The sustainability literacy questionnaire instrument has 16 items, with 8 positive statements and 8 negative statements that are randomly sorted. The STEM-PjBL learning questionnaire contained 11 items (item numbers 17-27) with 6 positive statements and 5 negative statements randomly sorted.

Table 6. Sustainability literacy indicators

No	Sustainability Literacy Indicators	Student Activities
1	Ecological principles and processes	Students can identify environmental problems and ecological processes that are not suitable.
2	Natural resources, human utilisation, and environmental degradation	Students can learn about using natural resources and the environmental damage they cause.
3	Consumption patterns	Students can regulate consumption patterns for products capable of causing environmental damage.
4	Household	Students can apply household waste treatment in the family environment.
5	Partisipasi	Students participate in group discussions to solve environmental problems.
6	Concerns	Students have concerns about the environmental damage that occurs.
7	Social responsibility	Students can participate to provide knowledge related to environmental issues to the community.
8	Control locus	Students are confident that by participating in preserving the environment, they can maintain the Earth's sustainability.

Based on the results of the calculation of the Aiken index in Table 7, the relevant and irrelevant values limited by the standard value V of 0.76 of the sustainability literacy questionnaire instrument resulted in 13 relevant items and 3 irrelevant items. Even so, the average result of the overall V value is 0.90, so it can be categorised as a high level of validity (Ozdemir, 2021).

The results of the analysis of the Aiken index on 16 question items of the sustainability literacy questionnaire instrument showed that three question items, 3, 11, and 15, were declared irrelevant. The irrelevant values in item numbers 3, 11, and 15 mean that the questionnaire items are not aligned with the sustainability literacy indicators, so they require improvement in the questionnaire question items. The improvement of the teaching module instrument needs to consider comments from expert validators. The expert validators' comments on the sustainability literacy questionnaire instrument are summarised in Table 8.

The refinement of the sustainability literacy questionnaire based on expert feedback underscores the importance of linguistic clarity and conceptual alignment in developing effective measurement tools for high school students. Negative statements that were initially confusing were revised to ensure transparency and reduce cognitive load, which is crucial for maintaining response accuracy among younger respondents. Experts also emphasized the necessity of representing each indicator with at least one well-structured item and ensuring that the language used is simple and age-appropriate. These improvements are in line with Nugroho et al. (2019), who highlighted the need for contextualized and culturally sensitive instruments in sustainability education, particularly when using a STEM approach based on local wisdom. Moreover, the use of clear and comprehensible language aligns with findings by Adam et al. (2021), who stressed that students' sustainability literacy is closely tied to their understanding of key concepts during science learning in schools. Chen et al. (2022) further support this by asserting that the validity of sustainability literacy instruments depends significantly on how well they

measure knowledge, attitudes, and behaviors through accessible and unambiguous statements. Thus, the revisions made to the questionnaire instrument enhance its construct validity and usability in capturing meaningful data on students' sustainability literacy within STEM-based learning environments (Nugroho et al., 2019; Adam et al., 2021; Chen et al., 2022).

Table 7. Results of the analysis of the Aiken index sustainability literacy questionnaire instrument

Item Number	Standard Value V	Value V	Conclusion
1	0.76	1.00	Relevant
2	0.76	1.00	Relevant
3	0.76	0.71	Irrelevant
4	0.76	0.86	Relevant
5	0.76	0.86	Relevant
6	0.76	0.86	Relevant
7	0.76	0.86	Relevant
8	0.76	1.00	Relevant
9	0.76	1.00	Relevant
10	0.76	1.00	Relevant
11	0.76	0.71	Irrelevant
12	0.76	1.00	Relevant
13	0.76	0.86	Relevant
14	0.76	1.00	Relevant
15	0.76	0.71	Irrelevant
16	0.76	1.00	Relevant

Table 8. Expert validator's comments on the sustainability literacy questionnaire instrument

Validator Comments	Responses
Some negative statements use confusing sentences.	Some negative sentences have been changed in sentence structure and the use of words to make them more transparent.
Make sure each indicator is measured with one representative statement.	Each indicator has a minimum of one sentence.
Use simple statements that are easy for students at the high school level to understand.	All statements have been checked, and sentences that are easy to understand have been ensured to be used.
The choice of the word rate/concentration can be improved.	The word level/concentration has been adjusted to the questionnaire statement.

Sustainability literacy pre-test and post-test instruments

The sustainability literacy pre-test and post-test are multiple-choice questions with indicators from Ozdemir (2021). This instrument uses 8 question indicators, producing 8 sustainability literacy pre-test questions (items 1-8) and sustainability literacy post-test questions (items 9-16) for each.

Based on the results of the calculation of the Aiken index, the relevant and irrelevant values limited by the standard value of V of 0.76 of the sustainability literacy pre-test and post-test instruments produced 16 relevant items, as summarised in Figure 1 (Aiken,

1985). The average result of the overall V value is 0.91, so it can be categorised as a high level of validity (Utami et al., 2024).

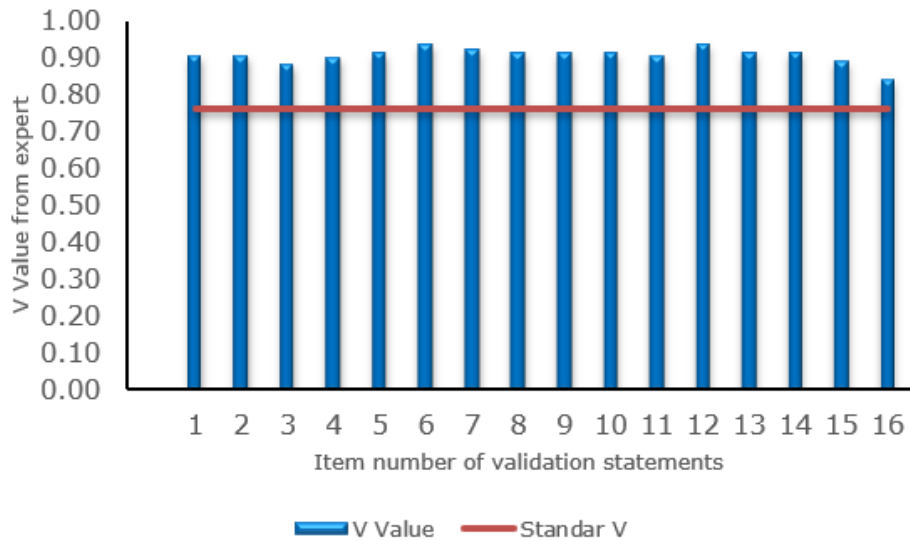


Figure 1. Aiken index graph of sustainability literacy pre-test and post-test instruments

The results of the analysis of the Aiken index on 16 question items used in the sustainability literacy pre-test and post-test instruments show that all items are relevant, meaning that the sustainability literacy pre-test and post-test instruments are aligned with the existing indicators and materials. Therefore, sustainability literacy pre-test and post-test instruments can be used to measure sustainability literacy skills at the data collection stage without any improvement. The comments of expert validators on the sustainability literacy pre-test and post-test instruments can be seen in Table 9.

Table 9. Expert validator's comments on sustainability literacy pre-test and post-test instruments

Validator Comments	Responses
The deceiving option and the correct answer must be the same length, but still clear.	The answer option has been checked, ensuring that it does not differ significantly in the length of the sentence.
Capital letters are not allowed in question sentences, such as 'find the WRONG answer in the following reading'.	The use of capital letters in the question sentence has been replaced according to the applicable rules.
The answer option should not be A, B, C, or D because it is not by high school standards; it can be changed to A, B, C, D, E.	The answer options are changed to A, B, C, D and E.
The choice of language and terms is consistent, so students have no misconceptions.	Each question item is researched and revised if there is a use of language and terms that are inconsistent in writing.

The expert validation of the sustainability literacy pre-test and post-test instruments revealed several technical and pedagogical refinements necessary to ensure the clarity, fairness, and standardization of the test items. Key revisions included ensuring that all distractors (deceiving options) and correct answers were similar in length to minimize test-

wise strategies and reduce cueing effects. Additionally, capitalized directives such as "find the WRONG answer" were revised to conform to proper formatting conventions, supporting readability and reducing unintended emphasis. The adjustment of answer choices to A, B, C, D, and E reflects alignment with national high school assessment standards. Consistency in the use of terminology and language across all items was also addressed to prevent student misconceptions—an essential factor for accurately assessing conceptual understanding. These revisions are consistent with Nugroho et al. (2019), who emphasize the importance of culturally and cognitively appropriate assessments in sustainability education. Adam et al. (2021) further highlight that literacy in sustainability requires not only accurate content but also assessments that minimize bias and linguistic confusion. Similarly, Chen et al. (2022) stress the role of well-constructed assessments in capturing students' knowledge, attitudes, and behaviors related to sustainability. As such, the validated instrument supports reliable measurement of learning gains and literacy development within the STEM-PjBL context.

STEM-project-based learning (STEM-PjBL)

The learning to be used is the STEM-PjBL model with the syntax of the EDP method proposed by Capraro and Jones (2013), detailed in Table 10.

Table 10. STEM-PjBL syntax with EDP method

No	Sintak's EDP (STEM-PjBL)	Student Activities
1	Identify problem and constraints	Students are asked to identify the problems presented. The issues identified can come from the environment, such as batik dye waste.
2	Research the problem	Students work in groups to research or find information related to the problems presented by various trusted sources.
3	Ideate (Develop a possible solution)	Students are looking for possible solutions to problems. Solutions can take the form of temporary problem-solving, human actions around waste pollution, or the creation of simple waste-cleaning tools.
4	Analyse idea (Select a promising solution)	Students identify initial ideas, which are analysed to choose the most feasible solution according to the given project criteria. At this stage, students also look for the advantages and disadvantages of each group's project design and consider samples that can be used to solve the problem.
5	Build, test and refine the prototype	After generalising the selection of the best possible solution, the students realised a product in the form of a simple waste purification device according to their idea.
6	Communicate and reflect	Students presented the results of the product, a simple waste purifier, and the practicum that was carried out. The criticism and suggestions obtained are used to reflect on their projects.

The instrument developed based on the STEM-PjBL stages is a questionnaire on the STEM-PjBL process.

STEM-PjBL questionnaire instrument

The questionnaire instrument in STEM-PjBL also uses the Likert scale. The STEM-PjBL questionnaire instrument has 12 items.

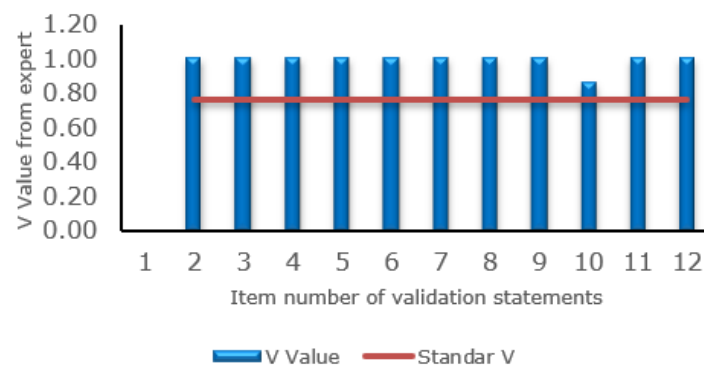


Figure 2. Aiken index graph from STEM-PJBL questionnaire instrument

Based on the results of the calculation of the Aiken index in Figure 2, the relevant and irrelevant values limited by the standard value V of 0.76, STEM-PjBL questionnaire instrument produced 16 relevant items. The average result of the overall V value is 0.99, so it can be categorised as a high level of validity (Utami et al., 2024). The results of the analysis of the Aiken index on 12 question items used in the STEM-PjBL questionnaire instrument showed that all items were relevant, meaning that the STEM-PjBL questionnaire instrument was consistent with the existing indicators. Therefore, the STEM-PjBL questionnaire instrument can be used for the data collection stage without any improvements. The expert validators' comments on the STEM-PjBL questionnaire instrument can be seen in Table 11.

Table 11. Expert validator's comments on STEM-PJBL questionnaire instrument

Validator Comments	Responses
Ensure each questionnaire statement represents the STEM-PjBL syntax of the EDP method.	One STEM-PjBL syntax of the EDP method has been included in at least one statement on the questionnaire.
Focus the statement on the relationship between stoichiometric learning and students' sustainability literacy skills.	The statement linked stoichiometric learning and students' sustainability literacy skills.

The validation of the STEM-PjBL questionnaire focused on ensuring the theoretical and contextual alignment of its statements with the core elements of the engineering design process (EDP) and the goals of sustainability literacy. Validators emphasized the importance of representing each stage of the STEM-PjBL syntax within the questionnaire, prompting a revision that ensured at least one statement reflects each EDP component. Additionally, the content of the items was refined to highlight the connection between stoichiometric learning and the development of students' sustainability literacy, thereby strengthening the instrument's construct validity. These improvements align with Shidiq et al. (2020), who noted that effective STEM implementation in chemistry education must be grounded in teachers' and students' understanding of interdisciplinary problem-solving processes. Moreover, as emphasized by Ahmad & Siew (2021), valid STEM-related questionnaires must not only measure exposure or attitude but also reflect the depth of engagement with STEM learning processes. Kartimi et al. (2021) also stressed the necessity of integrating contextual and competency-based dimensions into instruments to ensure their relevance in 21st-century learning environments. The validated questionnaire thus offers a sound basis for evaluating how well students experience and perceive STEM-

PjBL learning, particularly in fostering conceptual understanding and sustainability-oriented thinking in stoichiometry (Shidiq et al., 2020; Ahmad & Siew, 2021; Kartimi et al., 2021).

Instrument for observing student performance in practicum

This study has an instrument for observing student performance in practicum, summarised in 6 items. This instrument was made to observe how students perform in conducting practicum using 6 items that assess students from practicum preparation to data processing and conclusions.

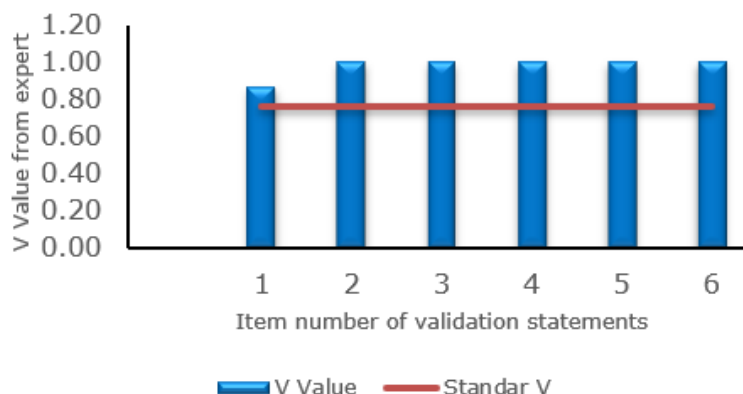


Figure 3. Aiken index graph from the student performance observation instrument in practicum

Based on the results of the calculation of the Aiken index for relevant and irrelevant values limited by the standard value of V of 0.76, the observation instrument of student performance in practicum produced 6 relevant items, as summarised in Figure 3. The average result of the overall V value is 0.98, so it can be categorised as a high level of validity (Utami et al., 2024). The results of the analysis of the Aiken index on 6 items used for student performance observation in the practicum show that all items are relevant, meaning that the instrument for observing student performance in the practicum is based on the existing indicators. Therefore, the instrument for observing student performance in practicum can be used for the next stage, namely, data collection without any improvement. The comments of expert validators on the instrument of observation of student performance in practicum can be seen in Table 12.

Table 12. Expert validator comments on student performance observation instrument in practicum

Validator Comments	Responses
The performance carried out by students can be detailed in more detail so that there is no assessment bias.	Each performance of students in the practicum is detailed in more detail so that the assessment becomes clearer.

The validation of the student performance observation instrument in practicum emphasizes the importance of detailed and objective assessment criteria to minimize bias during performance-based evaluations. Expert feedback highlighted the need to specify student actions more clearly, prompting revisions that provide detailed descriptors for each observed behavior during the practicum. This level of detail ensures that assessors have a shared understanding of what constitutes various levels of performance, thus enhancing

the reliability and fairness of the observation process. As noted by Shidiq et al. (2021a), well-structured observation instruments are essential in supporting innovative laboratory practices, particularly in contexts where students are encouraged to engage in hands-on inquiry and problem-solving. Furthermore, Anggreani et al. (2023) emphasize that clearly defined performance indicators in practical activities can help foster students' creative thinking and active engagement, especially when integrated with project-based or media-rich learning. The improvements made to the observation instrument contribute to a more valid and consistent evaluation of student competencies in STEM-based chemistry practicum settings (Shidiq et al., 2021b; Anggreani et al., 2023).

Water filtration project scoring rubrics

A simple water filtration assessment instrument assesses student projects designed and made in groups. Simple water filtration is a project carried out by students as a result of STEM-PjBL. This instrument has several parts, including planning (items 1-4), design and working methods (items 5-8), physical form of products (items 9-12), product innovation (items 13-16), and reports (items 17-20).

Table 13. Aiken index analysis results: assessment of simple clarifiers

Aspects	Item Number	Standard Value V	Value V	Conclusion
Including planning	1	0.76	1.00	Relevant
	2	0.76	1.00	Relevant
	3	0.76	0.86	Relevant
	4	0.76	0.86	Relevant
Design and working methods	5	0.76	1.00	Relevant
	6	0.76	0.86	Relevant
	7	0.76	0.71	Irrelevant
	8	0.76	0.86	Relevant
Physical form of products	9	0.76	1.00	Relevant
	10	0.76	1.00	Relevant
	11	0.76	1.00	Relevant
	12	0.76	0.86	Relevant
Product innovation	13	0.76	1.00	Relevant
	14	0.76	1.00	Relevant
	15	0.76	0.86	Relevant
	16	0.76	0.86	Relevant
Reports	17	0.76	1.00	Relevant
	18	0.76	1.00	Relevant
	19	0.76	1.00	Relevant
	20	0.76	1.00	Relevant

Based on the results of the calculation of the Aiken index in Table 13, for relevant and irrelevant values limited by the standard value V of 0.76, the simple water filtration assessment instrument produced 19 relevant items and 1 irrelevant item. Even so, the average result of the overall V value is 0.94, so it can be categorised as having a high level of validity. The results of the analysis of the Aiken index on 20 items of assessment of simple cleaning tools show that one item is declared irrelevant, namely item number 7. Item number 7 is an aspect of design and how it works. Irrelevant values in item number 7 mean that the assessment is not based on the indicators or material, so it requires.

Table 15. Results of the analysis of the Aiken index pre-test and post-test cognitive instruments

Type	Item Number	Standard Value V	Value V	Conclusion
Pre-test	1	0.76	0.98	Relevant
	2	0.76	0.92	Relevant
	3	0.76	0.96	Relevant
	4	0.76	0.96	Relevant
	5	0.76	0.98	Relevant
Post-test	6	0.76	0.98	Relevant
	7	0.76	0.92	Relevant
	8	0.76	0.96	Relevant
	9	0.76	0.96	Relevant
	10	0.76	0.98	Relevant

Based on the results of the Aiken index calculation in Table 15, for relevant and irrelevant values limited by the standard value V of 0.76, the cognitive pre-test and post-test instruments produced 10 relevant items. The average result of the overall V value is 0.96, so it can be categorised as a high level of validity (Susantini et al., 2025). The results of the analysis of the Aiken index on 10 question items used in the cognitive pre-test and post-test instruments showed that all items were relevant, meaning that the cognitive pre-test and post-test instruments were aligned with the existing indicators and materials. Therefore, pre-test and post-test cognitive instruments can be used for the next stage, namely, data collection, without any improvement. The comments of expert validators on the cognitive pre-test and post-test instruments can be seen in Table 16.

Table 16. Expert validator's comments on cognitive pre-test and post-test instruments

Validator Comments	Responses
Mr, a compound should not be written directly in the question, but can be used with Ar so learners can calculate Mr from a compound themselves.	The information in the question item has been changed from Mr to Ar.
The use of sentences can be corrected, such as paragraph layout, so it is not confusing.	The still confusing paragraph layout has been fixed.
The language rules can be used to observe the choice of diction.	The choice of diction has been researched and adapted to the rules of the language.

The refinement of the cognitive pre-test and post-test instruments focused on improving the clarity, accuracy, and relevance of each item to the targeted stoichiometry concepts. Validators emphasized the importance of encouraging students to calculate molecular mass (Mr) using the relative atomic mass (Ar) rather than providing Mr directly, thus promoting analytical thinking aligned with core stoichiometric skills. Revisions were made accordingly, along with improvements in paragraph structure and diction to enhance readability and avoid misinterpretation. These adjustments are crucial, as stoichiometry often presents cognitive challenges related to mole concepts, proportional reasoning, and chemical calculations. Previous studies also identified that students commonly struggle with

these abstract and quantitative aspects of stoichiometry, underscoring the need for valid and well-structured instruments. By addressing language precision and ensuring each item assesses core reasoning in stoichiometric problem-solving, the revised instrument contributes to more accurate measurement of students' conceptual understanding, aligning with previous research findings on the importance of (Kristiyanto et al., 2019; Yamtinah et al., 2022).

Overall, the validation process of the various instruments—ranging from teaching modules, student worksheets, questionnaires, observation sheets, to cognitive tests—demonstrates a systematic effort to ensure their quality, clarity, and alignment with the objectives of STEM-PjBL learning on stoichiometry. Revisions based on expert feedback have improved the instructional and assessment tools, particularly in terms of content accuracy, linguistic clarity, and pedagogical relevance. These improvements are supported by previous studies that emphasize the critical role of well-designed and contextually appropriate instruments in enhancing scientific literacy (Ekantini & Wilujeng, 2018), supporting performance-based assessment (Anggreani et al., 2023), and promoting sustainability-oriented learning (Nugroho et al., 2019; Adam et al., 2021; Chen et al., 2022). Additionally, the cognitive challenges inherent in stoichiometry demand valid tools that assess not only content knowledge but also students' reasoning and problem-solving abilities (Yamtinah et al., 2022; Kristiyanto et al., 2019). Instruments that are clearly structured and theoretically grounded such as the STEM-PjBL and sustainability literacy questionnaires are essential for capturing students' engagement with interdisciplinary learning (Shidiq et al., 2020; Ahmad & Siew, 2021; Kartimi et al., 2021). Thus, the validated instruments provide a robust foundation for both instructional implementation and further educational research in chemistry learning that integrates STEM and sustainability principles.

Following a series of expert validations and revisions based on the feedback received, all instruments including the teaching module, student worksheets, performance observation sheets, sustainability literacy questionnaire, and cognitive tests have been deemed valid and are ready for implementation in chemistry learning based on STEM-project-based learning (STEM-PjBL) on the topic of stoichiometry. These instruments have been carefully developed to ensure content accuracy, appropriate language use, and contextual relevance to promote 21st-century skills such as problem-solving, critical thinking, and scientific literacy. Therefore, the instruments are expected to effectively support meaningful, measurable, and contextualized learning experiences that help students better understand stoichiometry and its real-world applications.

Conclusion

Based on the results of the validation of eight instruments by 7 expert validators through FGD, all instruments were declared valid and included in the high category. The average V value of the eight instruments is higher than Aiken's V standard 0.76. Therefore, an instrument developed for STEM-PjBL learning, assisted by a simple photometer with LED RGB to measure students' sustainability literacy skills and learning outcomes, can be used. However, some items still need to be improved according to the comments of expert validators to obtain the ideal instrument as a data collection tool.

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