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Research Article:

Contemporary Hybrid Laboratory Pedagogy: Construction of a Simple Spectrophotometer with STEM Project-Based Learning to Introduce Systems Thinking Skills

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ABSTRACT

Hands-on laboratory activities are a vital aspect of chemistry education that can help students strengthen their understanding of chemistry's core concepts and applications. Nevertheless, during the COVID-19 pandemic, students and teachers could not access laboratories. Thus, innovative pedagogical approaches are required to meet these challenges. The current study, therefore, examines the use of contemporary hybrid laboratory pedagogy to construct a simple spectrophotometer by implementing Science, Technology, Engineering, and Mathematics (STEM) project-based learning to introduce systems thinking skills and measure the effectiveness of improving attitude. A quantitative approach, with one group pre-post design, was employed in this study. The subjects were 33 chemistry students from a state university in Bandung, Indonesia. A simple Atomic Absorption Spectrophotometer (AAS) was chosen as the topic of an engineering project given to students. The project was implemented over fourteen meetings designed in a hybrid laboratory activity. The students' worksheets, questionnaires on students' attitudes toward systems thinking skills, and a questionnaire on student attitudes toward STEM-project-based learning were used as research instruments. Additionally, interviews with selected students further supported the quantitative data. Following the intervention, a RASCH: racking and stacking analysis revealed that two of the eight systems thinking skills indicators showed noticeable results. Other results uncovered that the student-made simple AAS had an accuracy of 95.3% compared to commercial AAS. This study also demonstrated that students had a negative attitude toward implementing STEM project-based learning. In contrast, students' attitudes towards systems thinking skills indicated positive results. Challenges and opportunities for further research are also discussed in this paper.

Keywords: Hybrid laboratory pedagogy, STEM learning, system thinking skills, simple AAS

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INTRODUCTION

The COVID-19 pandemic has forced the global learning process to change from face-to-face to online (Adams et al., 2022; Nasution, 2022). Online learning seems to be a promising solution for teaching and learning activities during the pandemic (Basilaia & Kvavadze, 2020; Fuad et al., 2020; Juanda et al., 2021; Murphy, 2020). The use of technology in online learning has further significantly affected pedagogy since it brings flexibility, which is a critical factor in creating an effective online learning environment (Sampson et al., 2018; Tan et al., 2022). However, online learning implementation is not without challenges. The sudden implementation of the policy certainly causes the unpreparedness of students and educators (Juanda et al., 2021; Shidiq et al., 2021b). Specifically, online learning conducted remotely poses a challenge for chemistry educators to carry out hands-on laboratory activities (Destino et al., 2021). This issue also occurs in all Science, Technology, Engineering, and Mathematics (STEM) education and needs to be considered.

In chemistry education, online learning and advanced technology are not new. Many chemistry educators and researchers have implemented online learning before the COVID-19 pandemic, such as online organic chemistry learning (King et al., 2019), online chemistry learning using CDs and computer simulations (Hoole & Sithambaresan, 2003; Kennepohl, 2001), and blended chemistry learning to improve student learning achievement (Bernard et al., 2017). Nonetheless, carrying out online laboratory activities to provide hands-on skills for students remains challenging.

Hands-on laboratory activities are a way for students to gain experience in learning how to use chemical equipment and instrumentation (Enneking et al., 2019). At the university level, laboratory activities using various Spectrophotometer instruments and other modern instrumentation are tough to be carried out during online learning (Shidiq et al., 2020b, 2021a, 2020c). For this reason, an innovative pedagogical approach is needed. One alternative proposed is the construction of a simple spectrophotometer in hybrid laboratory activities using STEM project-based learning.

Furthermore, the unavoidable online learning process during and after COVID-19 and the need for hands-on chemistry laboratory activities that need to be fulfilled are becoming this research's focus. Therefore, this study aims to use contemporary hybrid laboratory pedagogy to construct a simple spectrophotometer by implementing STEM project-based learning to introduce systems thinking skills and measure the effectiveness of improving attitude. This study is expected to be an alternative to the current laboratory pedagogy approach, combining online and offline learning that emphasises hands-on activities. Moreover, most research focuses on increasing student knowledge through various pedagogical laboratory treatments, but little attention is paid to students' attitudes toward the treatment (Manunure et al., 2019). At the same time, students' attitudes toward learning will affect their learning achievement (Fabian et al., 2016; Yildirim, 2017). By investigating students' attitudes towards the treatment, it is hoped that this study will contribute as a reference for teachers to use appropriate pedagogical approaches to increase students' knowledge and attitudes.

LITERATURE REVIEW

Hybrid Laboratory Pedagogy

Chemistry educators agree that laboratory activities are vital in chemistry learning (Kennepohl, 2021; Reid & Shah, 2007; Shidiq et al., 2020c). It is because laboratory activities are not only for developing hands-on skills but also for constructing chemical concepts (Irby et al., 2018). Some researchers have reported that laboratory activities arouse strong student interest in learning chemistry (Hascher et al., 2004). It can also enhance students' learning abilities as they help the students understand the subject matter (Niaz, 2005). Another stated that students felt more motivated when doing laboratory activities in chemistry learning (Ramos et al., 2016). Some of these studies suggest the importance of using the laboratory as a pedagogy – *laboratory-based pedagogy* – to cultivate students' interest and build their concept of chemistry knowledge and skills (Huri & Karpudewan, 2019; Irby et al., 2018; Karpudewan et al., 2011).

On the other hand, when schools and universities were closed due to COVID-19, chemistry educators could not carry out laboratory activities freely. Then, it triggered the shift from conventional laboratory activities to hybrid and online. Yet, implementing fully online laboratory activities is often deemed a significant obstacle to developing effective learning (Patterson, 2000). Apart from that, the issue of the safety of student activities and pedagogical constraints that consider the laboratory atmosphere cannot be imitated outside the laboratory are other obstacles (Kennepohl, 2001). Students who conduct laboratory activities outside a natural laboratory setting and are not supervised by a laboratory instructor also cannot acquire the necessary laboratory skills (Boschmann, 2003). Hence, hybrid laboratory pedagogy is becoming an alternative to help students achieve the expected minds-on and hands-on competencies in chemistry education (Kelley, 2021; Zhang et al., 2020). In addition, the growing awareness related to ESD (Education for Sustainable Development) makes conventional laboratory activities need to be reduced to realise green chemistry for ESD (Karpudewan et al., 2012c, 2016; Karpudewan & Kulandaisamy, 2018).

Construction of a Simple Spectrophotometer with STEM Project-Based Learning

Researchers have developed various ways to teach spectrophotometer principles. One of them is by making a simple spectrophotometer. A wide variety of simple spectrophotometers have been created, such as DVD Uv-Vis spectrophotometers (Wakabayashi & Hamada, 2006), flame spectrophotometers (Lafratta et al., 2013; Moraes et al., 2014), and visible light spectrophotometer (Albert et al., 2012). Nevertheless, simple spectrophotometer instruments were constructed mainly on simple UV-Vis spectrophotometers (Clippard et al., 2016; Diawati et al., 2018). The construction of other types of simple spectrophotometers, such as the Simple Atomic Absorption Spectrophotometer (AAS), is another opportunity that can be considered (Shidiq et al., 2020c).

In this case, STEM-project-based learning (STEM-PjBL) integrates engineering projects into the curriculum and can be implemented to construct simple AAS. There has been much integration of STEM into learning, and laboratory activities carried out by researchers

(Khatri et al., 2017), such as the STEM implementation in high school lessons (Saptarani et al., 2019) and various laboratory and learning activities (Blotnicky et al., 2018; Porter, 2018; Shin et al., 2018). However, the STEM-PjBL implementation in hybrid laboratory activities – especially in Indonesia – is rarely conducted.

Project-based learning often consists of only a few problems students need to solve (Capraro et al., 2013; Shidiq et al., 2020a, 2021a). Meanwhile, STEM-PjBL provides the contextual-authentic necessary experiences for students to learn and build strong and meaningful science, technology, engineering, and mathematics concepts supported by language, social studies, and the arts (Han et al., 2016; Kartimi et al., 2021; Togou et al., 2020). STEM-PjBL also builds on engineering design as a foundation on which students bring their fragmented knowledge of science, technology, and mathematics to solve significant real-world problems for sustainable development (Burrows & Slater, 2015; Capraro et al., 2013; Capraro & Corlu, 2013).

Further, implementing STEM-PjBL in chemistry education that integrates various disciplines and connects multiple aspects of social life requires skills to understand, identify, analyse, organise and evaluate multiple aspects holistically (Arnold & Wade, 2015; York et al., 2019). Accordingly, systems thinking skills, the primary skills in ESD that shift from disciplinary content to a more integrated and holistic understanding, are suitable to be introduced and improved using STEM-PjBL (Burmeister et al., 2012; Jegstad & Sinnes, 2015). Moreover, a framework that uses systems thinking skills in chemistry education places students at the center of the chemistry education system, suggesting tools and approaches to help teachers and curriculum developers see the interconnections among the different components of learning chemistry (Flynn et al., 2019; Mahaffy et al., 2019; Mahaffy, Brush, et al., 2018). Consequently, implementing STEM-PjBL in chemistry learning and laboratory activities to introduce systems thinking skills is promising.

Systems Thinking Skills (STS)

Systems thinking and sustainability are growing topics in chemistry education that many experts are researching. Mahaffy and colleagues (2018) reveal that systems thinking is an approach emphasizing the interdependence between dynamic system components (Mahaffy, Brush, et al., 2018; Mahaffy, Krief, et al., 2018). In line with Mahaffy et al., Hammond (2002) defines systems thinking as an approach to researching and learning about concepts from a holistic perspective. Meanwhile, Jegstad and Sinnes (2015) describe systems thinking as the skills to analyse complex systems across different domains (society, environment, economy, and others), cascading, inertia, causal loops, and other related systemic features for sustainability issues and sustainability problem-solving frameworks. Further research unveils a model of sustainable chemistry education that puts systems thinking as the primary skill that students must have (Assaraf & Orion, 2005; Jegstad & Sinnes, 2015; Lewis et al., 2014).

Since it was coined by Richmond (1994), the term systems thinking has been defined and redefined in many different ways. Redefining systems thinking in many fields is helpful as an answer to the elusive concept of systems thinking to allow it to be measured relatively easily (Arnold & Wade, 2015). Several definitions of systems thinking previously described indicate two defining tendencies: systems thinking as an approach and skills. A special issue in the *Journal of Chemical Education*, which focuses on systems thinking in chemistry education, has provided several examples of systems thinking that can be combined with the chemistry curriculum content both as an approach and skills (Assaraf & Orion, 2010; Flynn et al., 2019; Mahaffy, Krief, et al., 2018; Talanquer, 2019).

In this regard, this research defines systems thinking as a skill that can accommodate the learning outcomes of the course in this study. Here, building students' capacity to integrate systems thinking skills into chemistry problem-solving can generate new opportunities for innovation in learning. It can help to stimulate and inspire further work and broader research in chemistry education to introduce and improve students' systems thinking skills and a deeper and more interrelated understanding of STEM courses (Evans et al., 2017; Mahaffy, Brush, et al., 2018; Mahaffy, Krief, et al., 2018).

In this study, indicators of systems thinking skills were adapted from Assaraf and Orion (2005). This study then defines the AAS instrument as a system. These AAS instruments are composed of many vital sub-system components, such as the light source, combustion, and detection sub-systems. Besides, systems thinking skills require students to have a holistic view of the components of dynamic systems, including connections and interdependences and their interaction with other systems in the community's social life. Through the construction of a simple AAS project provided, students are trained not only to understand the AAS system but also to describe the relationship of the AAS system with the context of the daily life system as a tool to solve various global problems and challenges. The indicators of systems thinking skills and their relationship to the STEM-PjBL stages are shown in Table 1.

Table 1. Relationship of STEM-PjBL stages to STS

No	STEM-PjBL stages	STS indicators
1	Identifying problems and constraints	• Students acquire the ability to identify the AAS system components and processes.
2	Researching the problem	• Students can identify relationships and characteristics between components in the AAS system.
3	Ideating (Developing a possible solution)	• Students learn to organise the composition of alternative components used in the simple AAS construction process in a related framework.
4	Analysing idea (Selecting promising solution)	• Students develop the ability to generalise from various alternative solutions to replace components in simple AAS systems.
5	Building, testing, and refining	• Students develop the ability to understand the nature of the cycle in the AAS system development and the context of daily life related to the AAS system. • Students develop the ability to identify dynamic relationships in the constituent components of the AAS system and with the systems of daily life.

(Continue on next page)

Table 1 (continued)

No	STEM-PjBL stages	STS indicators
6	Communicating and reflecting	• Students understand the hidden dimensions they are unaware of from the simple AAS system. • Students learn to think temporally and retrospectively, collaborate, and make predictions of opportunities to realise their simple AAS design into a prototype.

METHODOLOGY

Research Design and Subjects

A quantitative approach, with one group pre-post design, was used in this study. This research was conducted at the Chemistry Education Department at one state university in Bandung in the even semester of 2021. This research was carried out for 14 weeks. The research design employed was deemed appropriate and acceptable to identify changes that occurred before and after the intervention on students.

The sampling technique in this study was purposive sampling by choosing a class taking the Chemistry Separation and Measurement Practicum Course in the fourth semester with two credits (2 × 170 minutes). This subject was selected since there were laboratory activities to introduce various modern chemical instruments, including AAS. A total of 33 ($N = 33$; 7 male, 26 female) chemistry students participated in this study. This research has also received official permission from the university where the research was carried out. Additionally, the students involved in this study were those who had given informed consent. The one-group pretest-posttest experimental design utilised in this study is illustrated in Table 2.

Table 2. Research design

Pre-test	Intervention	Post-test
Students complete an attitude questionnaire towards STS and STEM-PjBL	Implementation of Hybrid Laboratory Pedagogy to construct a simple spectrophotometer by implementing STEM-PjBL to introduce systems thinking skills and measure the effectiveness of improving attitude	• Students complete the same attitude questionnaire on STS and STEM-PjBL as in the pre-test • Post-test to determine the STS mastery • Interviews

Eight questions about students' attitudes towards STEM-PjBL and 16 questions about students' attitudes toward STS were given during the pre-test and post-test. It was intended to determine the effectiveness of increasing students' attitudes towards STS and STEM-PjBL. After the intervention, a post-test with eight questions was used to determine students' STS mastery. Moreover, interviews were conducted to reveal students' views on the intervention.

Instruments

Four instruments were utilised in this study: students' worksheets, a questionnaire of student attitudes towards STEM-PjBL, a questionnaire of student attitudes towards systems thinking skills, and a post-tests instrument. Student worksheets were used to guide and document the work of students. This worksheet was constructed according to the learning stages and was only used in the first three meetings, which were fully online synchronous meetings. The use of this worksheet was also to make it easier for students to discuss and collaborate in designing their simple AAS instrument. The example of questions on the worksheet is presented in Table 3.

Table 3. Example questions on students' worksheets

No	Stages	Example of questions
1	Identifying problems and constraints	Draw your system design of the relationship between the AAS instrument and the context of everyday life!
		Identify various problems and constraints that might occur in developing a simple AAS!
		Identify various things in everyday life that require AAS as an analytical instrument!
2	Researching the problem	After identifying the problems and obstacles to developing simple AAS, look for information to solve problems and obstacles that might arise!
		What are the functions and characteristics of the components that make up AAS?
		How was the development of simple spectrophotometry instruments previously carried out?

The questionnaire on student attitudes towards STEM-PjBL was adapted from Frank et al. (2007). The questionnaire consisted of four positive and four negative statements about the STEM-PjBL implementation. Meanwhile, the questionnaire on student attitudes toward systems thinking skills was adapted from Gero and Zach (2014). This questionnaire encompassed eight statements of high systems thinking skills and eight statements of low systems thinking skills. This questionnaire instrument can be seen in Appendix A. Then, the post-test instrument was constructed based on indicators of systems thinking skills (Assaraf & Orion, 2005). This instrument comprised nine open-ended questions. Student answers were given a score according to the assessment rubric that experts had previously validated. The questions in this post-test can be seen in Appendix A.

Furthermore, the Aiken Formula tested all the instruments used in this study for content validity. Calculating content validity with the Aiken Formula has a validity standard following the determining variable: the number of validators and the number of validity-determining criteria used. The more the number of validators and the greater the number of criteria used, the easier it is to achieve the standard value for validity (Aiken, 1980; Aiken 1985). This study also involved six validators (raters) who were lecturers with expertise in chemistry and chemistry education and five validity criteria. The Aiken formula used is:

$$V = \frac{S}{[n \times (c-1)]}, \text{where } S = \sum ni(r - \ell o)$$

Where, *V* = the validity index from Aiken; *c* = the number of categories/criteria; ℓo = the lowest category; ni = the number of raters who chose criterion *i*; r = Criteria to *i*; and n = the total number of raters.

Based on Aiken's validity table for six validators with five validation criteria, the standard minimum validity criterion is 0.79. Thus, items with a validity value below 0.79 are not invalid, and above are valid. In this study, after several revisions, all the instruments used were declared valid with a validity value of >0.79.

Additionally, to test the agreement of the validators used, an analysis of the Many Facet Rasch Model (MFRM) utilising the Facet software was carried out. These tests determine consistency between raters, provide more precise information, and give valuable results about what is being assessed (Sumintono & Widhiarso, 2014a, 2015; Sunjaya et al., 2021). The MFRM test results are briefly shown in Table 4.

Table 4. Many Facet Rasch Model (MFRM) results

Instrument		Strata value	Reliability	Exact agreements	Expected agreements
STEM-PJBL questionnaires	Rater	4.45	0.91	38.3%	40.8%
	Item	5.95	0.92		
STS questionnaires	Rater	4.16	0.89	42.5%	43.8%
	Item	4.57	0.91		
Worksheets	Rater	4.48	0.92	31.7%	26.7%
	Item	5.41	0.94		
Post-test	Rater	5.15	0.93	45.5%	42.0%

The test results presented in Table 4 state that the rater's reliability index was more than 0.89, and the reliability of the items was more than 0.91, meaning that the rater's and item's reliability were in a suitable category. It is also reinforced by the lowest strata value of 4.16, indicating that the raters' results were reliable. Moreover, the exact and the expected agreement results are good if >40%. However, the worksheet data showed smaller results, demonstrating that the raters did not quite agree with the worksheet instrument (Chan et al., 2021; Gordon et al., 2021; Sunjaya et al., 2021). The data presented was the validation of the instrument's initial form. The rater's disagreement then became the focus of revising the instrument used. Therefore, in testing the validity after three-time revisions, the rater's agreement increased sharply.

The post-test instrument's validity and reliability were also tested with the Item Response Theory (IRT) approach using the Rasch Model Analysis with Winstep software. The Rasch model converts raw ordinal-type data using probabilities and logarithms into equal-interval scale data called logit (log odd units) (Adams et al., 2022; Sumintono & Widhiarso, 2015; Sunjaya et al., 2022). The instruments studied were Self-Rating Questionnaire (SRQ-20). The data were analysed to measure statistical items and find out the mean square ($0.5 < MNSQ < 1.5$), z-standard ($-2.0 < ZSTD < +2.0$), Pt-measure correlation ($0.4 < \text{Pt Measure Corr} < 0.85$), the relationship between items (unidimensionality), the questions' reliability, and the person's reliability (Purnami et al., 2021).

The test results on the post-test instrument revealed that the MNSQ was at 0.62–1.34 ($0.62 < MNSQ < 1.34$), indicating that all items were within the acceptable range. Z-standard scores ranked –1.9 to 1.4 ($-1.9 < ZSTD < +1.4$). It suggests that all items based on ZSTD were fit. Then, the Pt-measure correlation was 0.34 to 0.69 ($0.34 < \text{Pt Measure Corr} < 0.69$). This result denotes those two items did not meet the item criteria; however, other items fit the three criteria. In addition, the post-test questions showed that the raw variance explained by the measure was 39.5%, above 20%. It implies that this test instrument was valid and could measure various variables. In the item reliability test, Pearson and Cronbach's alpha were 0.91, 0.51 and 0.54. These results signify strong item reliability but a relatively weak interaction between person and item.

Interview

In this study, interviews were conducted after the intervention was carried out. This interview was conducted to reveal students' opinions regarding the intervention. Five students were purposively selected to be interviewed. The selection of these five students was based on their full involvement in the simple AAS prototype construction process. This semi-structured interview was conducted for about 15 minutes per student. The questions asked during the interview were:

1. In your opinion, what is the difference between the simple AAS laboratory practicum and the laboratory practicum on the previous instrument?
2. How did the model implement in a simple AAS practicum with the project help you to understand the AAS instrument in more depth?
3. In your opinion, which part of the project contributed to training knowledge and skills in the STEM field?
4. In your opinion, how does the given project train you to think holistically?
5. How does the applied model affect your perspective on the AAS instrument?

The data obtained from the interviews were then transcribed and analysed qualitatively. After the interview was completed, students were allowed to write their answers on the sheets provided to see their answers' consistency.

Hybrid Laboratory Setting

A hybrid laboratory setting was carried out by applying the *Engineering Design Process* (EDP) as a STEM-PjBL stage (Capraro et al., 2013). EDP systematically uses mathematics, science and technology concepts to solve complex problems. In this case, applying engineering that deals with real-world issues can provide an excellent context for illustrating concepts beneficial to students' daily lives (Basham & Marino, 2013). In addition, according to Katehi et al. (2009), the EDP definition as a "habit of mind" requires the following skills: (1) systems thinking, (2) creativity, (3) optimism, (4) collaboration, (5) communication, and (6) attention to ethical considerations. This habit of mind can be incorporated into everyday classroom environments and other instructional activities (Katehi et al., 2009). The stages undergone are depicted in Figure 1.

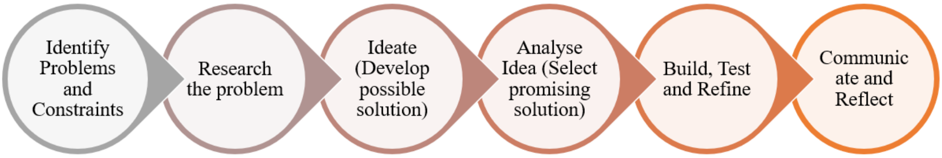

Figure 1. Stages of the engineering design process

These stages were implemented to construct a simple AAS as a STEM project given to students. Consequently, clear project criteria and constraints were needed to guide students in completing the project. The criteria and project limitations are shown in Table 5.

Table 5. STEM project criteria and constraints

Criteria	Constraint
1. Having a detection accuracy and repeatability function close to commercial AAS 2. Consisting of at least three main components (light source, sample combustion Bunsen, and detector) 3. Using easy-to-get household components (simple) 4. Easy to carry and move (portable) 5. Having an attractive design (visually appealing) 6. It can be used as a tool that contributes to solving problems in everyday life	1. Simple AAS construction budget of a maximum of IDR 3,000,000 (inexpensive)

Moreover, setting the conventional laboratory activities needs to be done to adjust the needs of laboratory activities in a hybrid. In this study, students were given a project to construct a simple AAS. There were two stages to complete this project; the first stage was to develop a simple AAS design. At this stage, online lectures were carried out through zoom meetings for 2 × 170 minutes. The next step was to construct a simple AAS prototype. This second stage was a structured project task evaluated weekly. The adequate time required for students to complete this project was 14 weeks. The detailed arrangement of laboratory activities is displayed in Table 6.

Table 6. Hybrid laboratory activities setting

Week	Stages	Activities	Pedagogical strategy
1st	Identifying problems and constraints Research the problem Ideating (Developing a possible solution)	In the first week, it was carried out for 2 × 170 minutes using Zoom Meeting. Students were divided into six groups, each developing a simple AAS design. To help students complete their projects, student worksheets were provided containing project criteria and limitations and assignments they needed to meet according to the STEM-PjBL stages. In this first week, students had also been looking for information related to household items, allowing them to be used as a substitute for commercial AAS components. The similarity of functions was the reference for students to do a simple component search.	Synchronous: Lecture
2nd	Analysing idea (Selecting promising solution) Building, testing, and refining	In the second week, it was carried out for 2 × 170 minutes using Zoom Meeting. Online activities focused on analysing alternative household tools they had previously identified. Consideration of function, compatibility, and cost became the determining factors of their choice. Each option was then developed as a simple design. It was later tested for design feasibility in front of their classmates.	Synchronous: Lecture
3rd	Communicating and reflecting	The third meeting was held for 2 × 170 minutes using Zoom Meeting. The meeting focused on each group's presentation of a simple AAS design. Each group reflected on its design based on discussions conducted in the classroom. In addition, they needed to determine the most promising simple AAS design to be later realised into a simple AAS prototype.	Synchronous: Lecture
4th	Identifying problems and constraints	After agreeing on a simple AAS design to be used as a prototype, in week 4, students repeated the problem identification stage. However, this stage focused on identifying their problems in realising a simple AAS prototype.	Asynchronous: Structured task
5th	Research the problem	At this stage, students searched for possible solutions to the problem and planned a simple AAS prototype completion time.	Asynchronous: Structured task

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Table 6 (continued)

Week	Stages	Activities	Pedagogical strategy
6th – 8th	Analysing idea (Selecting promising solution)	At this stage, students were asked to bring the design they had designed, along with a variety of alternative options of other possibilities, to be consulted with the closest engineering workers whom they would help complete their project. Some workers they met were: electric welding workers, workers in the electrical field, and workers in the wood field, and they took sellers of various tools they needed.	Asynchronous: Structured tasks and face to face: progress reports
9th – 13th	Building, testing and refining	After receiving input from various workers, students completed a redesign and contracted their simple AAS. Their simple AAS was tested at this stage and compared with commercial AAS. Students then came to the laboratory to make sample solutions and standards for testing.	Face-to-face at the laboratory and asynchronous
14th	Communicating and reflecting	In week 14, students communicated their simple AAS construction results to class members.	Synchronous: Presentation

Data Analysis

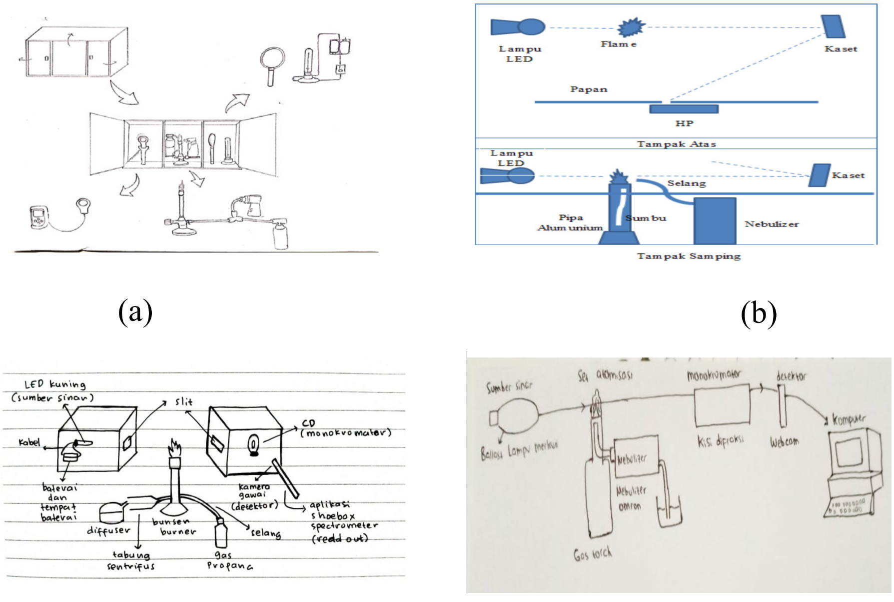
Data obtained from questionnaires on students' attitudes towards STS and STEM-PjBL and data from the post-test were analysed quantitatively. In the questionnaire on student attitudes towards STS and STEM-PjBL, quantitative analysis was carried out using the RASCH model approach with the racking and stacking method (Sumintono & Widhiarso, 2014b, 2015; Sunjaya et al., 2021). It is common to compare the results of the groups before and after the intervention with the *t*-test. However, this test had not been able to provide data analysis of the difference between the mean individual and item levels. Hence, the Rasch approach was applied, processing ordinal data transformed into interval logits so that the occurring differences could be known with high precision. In this regard, data racking analysis was employed to find the differences at individual levels, while stacking data analysis was used to find the differences at the item level (Adams et al., 2022; Laliyo et al., 2022). This analysis was carried out utilising the WINSTEPS software. Furthermore, the data obtained from the post-test results were processed using descriptive statistics to describe the data distribution and calculate the proportion of students' mastery of systems thinking skills in each indicator. At the same time, the data obtained from student worksheets and interviews were analysed qualitatively. This qualitative analysis was performed by documenting, transcribing, and comparing the consistency of students' answers.

In this study, a simple AAS prototype was produced, which was constructed by students. To test this prototype's performance and its characteristics, it is necessary to have comparative data from the AAS laboratory. Therefore, a quantitative data analysis technique by comparing the measurement results using a simple AAS prototype with laboratory AAS was employed in this study. Laboratory AAS instruments under the brand name Perkin Elmer PinAAcle 900T that have been calibrated and are from standardised laboratories were used as comparative data. A simple AAS prototype's percent error and characteristics could then be identified based on comparative data.

RESULTS

Simple AAS Design

Through the worksheet instrument distributed to each student to be filled in with the group, the documentation of simple AAS design data was obtained as a product produced in the first three meetings. This meeting was conducted synchronously through a Zoom Meeting. Besides that, the data that could be obtained from the worksheet was the design of simple tools to be used and the budget they proposed to construct the prototype. The design of each group is illustrated in Figure 2.



(a)

(b)

(c)

(d)

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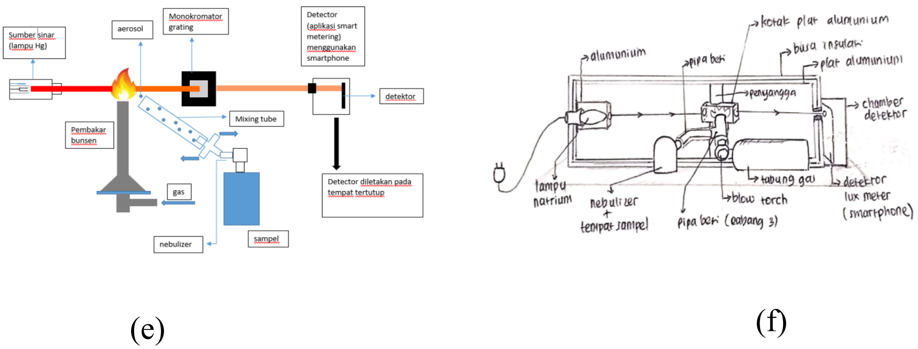
Figure 2 (Continued)



(e) (f)

Figure 2. Simple AAS design of six groups (a, b, c, d, e and f)

Figure 2 depicts a simple AAS design developed by six groups of students. Each design systematically represented the student's thinking process, from thinking about how the components worked to finding simple tools with similar working principles and conducting a cost affordability analysis according to the given constraints. Based on the results of the presentation and consideration of the criteria and constraints set, design (f) was chosen as the most likely design to be constructed as a simple AAS prototype. However, the students' discussions with the workers involved resulted in significant changes to the plan to be realised in the simple AAS prototype. The primary obstacle was the atomisation set system. They struggled to combine sample vapors with gaseous fuel. The revised simple AAS design is portrayed in Figure 3.

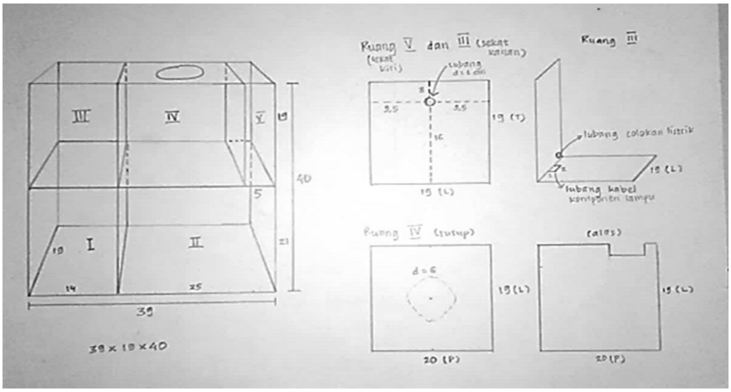


Figure 3. Revised simple AAS box design

Figure 3 exhibits the influence of face-to-face meetings between students and informants who were workers in several fields. It could provide technical considerations to students to determine the best choice of simple tools.

Simple AAS Construction

The construction results of a simple AAS prototype are demonstrated in Figure 4.

Figure 4. Simple AAS prototype

Figure 4 portrays a simple AAS prototype constructed using a sodium lamp, burner room, and lux meter detector. Lux meters had previously been used by researchers for detectors on simple Uv-Vis with a Green Laser Pointer light source to measure the concentration of coloured solutions (Diawati et al., 2018). This simple AAS specification is presented in Appendix B. The cost incurred to construct this simple AAS was IDR1,890,951. Besides, additional costs were needed for welding and the services of other workers who helped students in the amount of IDR1,244,000, so the overall cost was IDR3,134,951. This total cost slightly deviated from the total cost limit of IDR3,000,000 (project constraint).

Simple AAS Prototype Performance

The results of a simple AAS prototype constructed by students were used to measure sodium concentration in water. The prototype was tested and compared repeatedly to get good results in approaching commercial laboratory AAS. This data comparison test was carried out in a commercial laboratory using AAS with the Perkin Elmer PinAAcle 900T brand. The simple AAS prototype had not shown good measurement results in the first and second tests. However, in the third test, a simple AAS prototype already showed results that could be compared with commercial AAS. The measurement results of the standard curve by the prototype are displayed in Figure 5. The results of sample concentration measurements are shown in Table 7.

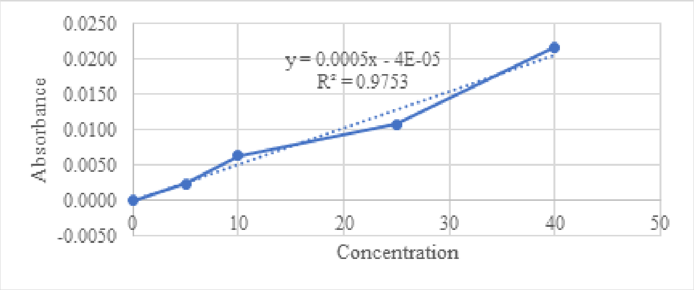


Figure 5. Calibration curves generated by a simple AAS prototype

Table 7. Measurement of sample concentration

Sample	R-square	Simple AAS	AAS lab	% error
Sample 1A	0.9753	39.488	19.23	105.347
Sample 1B		66.090	23.56	180.518
Sample 2A		30.466	18.73	62.6609
Sample 2B		35.466	33.87	4.71485

The test results using commercial AAS in this study were utilised as a benchmark to determine the accuracy and percentage of errors. Of the three tests for each sample, prototypes with lux meter detectors could only meet the accuracy criteria above 95% in the first trial. Compared to other simple Spectrophotometer test results, the results were already promising.

The test results of a simple flame photometer developed using a photodiode detector to measure sodium concentration in beverages showed an accuracy test result of 94.32% (Lafratta et al., 2013). Another study that developed FES (Flame Emission Spectrophotometer) with a fiber optic detector and connected with a computer to measure sodium samples from various samples disclosed varying accuracy results from 96%–99% (Néel et al., 2014). The consequences of a study using a flame test with an RGB image reading approach (red, green, blue) to determine sodium concentration in seawater and coconut water samples revealed an accuracy of 98.25% and 85.42%. Comparing research results using almost the same approach, the simple AAS prototype produced an accuracy of 95.28%, which could be categorised as good.

Comparison of Characteristics

Table 8 presents the comparison data between a commercial AAS and a simple AAS prototype. The most noticeable difference was in the accuracy and working area of the commercial AAS, which was better and more sensitive. Nevertheless, a simple AAS prototype has already given good results as a learning support instrument.

Table 8. Comparison of AAS characteristics

Component	AAS instrument	
	Commercial	Simple AAS prototype
Light source	Cathode (sodium) hollow and discharge lamp without patented electrodes	Philips SON-T Natrium Lamp 70 Watt
Monochromator	Littrow design with a motorised drive for automatic wavelength and peak selection	-
Detector	Photomultiplier tube (Segmented solid-state detector with a wide range, including a series of low-noise CMOS charging amplifiers)	Lux Meter LX1010B
Dimension	95 × 73 × 68 (cm)	39 × 19 × 39 (cm)
Accuracy	Based on accuracy calibration	95.28%
Percent errors	Based on accuracy calibration	4.71%
Working area	0.6–10 mg/L	30–80 mg/L

Results of Racking and Stacking Questionnaire

The data obtained from the pre-test and post-test regarding students' attitudes towards STS and STEM-PjBL were analysed using the racking and stacking techniques. The stacking results data is shown in Table 9.

Table 9. The stacking results of student attitudes towards STS and STEM-PjBL questionnaire

	Pre-test mean	Post-test mean	Difference	p^*
STS	+1.78 (+0.84 to +3.25)	+1.87 (+0.67 to +4.65)	0.09	<0.01
STEM-PjBL	+0.49 (–0.34 to +3.41)	+0.44 (–0.09 to 1.26)	–0.05	<0.01

Another result was attained from racking and stacking analysis in this study. Stacking analysis was used to obtain the mean difference by combining two databases: the pre-post-test assessment. By applying the Rasch model to the measurement results, a *logit value person* (LVP) was obtained, which showed how good the student's skills were. Lower grades, such as logit –0.51, mean that the student's ability is inadequate, while a higher value, i.e., a positive logit, indicates that the student's abilities are adequate or good. This type of analysis is called individual-centred statistics, which informs the situation of the student's abilities. Meanwhile, racking analysis was utilised to compare the difficulty of the questions (logit value of the question or logit value item (LVI) in pre-test and post-test situations (Adams et al., 2022; Chan et al., 2021; Laliyo et al., 2022; Sunjaya et al., 2021).

Table 9 also illustrates the stacking results of student attitudes toward STS and STEM-PjBL questionnaires. These results uncovered that the mean LVP of STS for the pre-test was +1.78, and the mean LVP of STS after intervention (post-test) was +1.87, so the difference was 0.09. Therefore, the interventions carried out had a slightly noticeable effect on improving students' attitudes toward STS. Further, an overall view related to the student's attitude towards STS could be seen through the Wright map. Figure 6 then depicts the Wright map results of the pre-test (R) and post-test (S) of the LVP attitude toward STS. For example, the attitude toward the STS LVP of R14 was +2.01, and after the intervention, the LVP of S14 was +4.65. It indicates an increase in two logit scales, meaning that the student had an increased attitude towards STS.

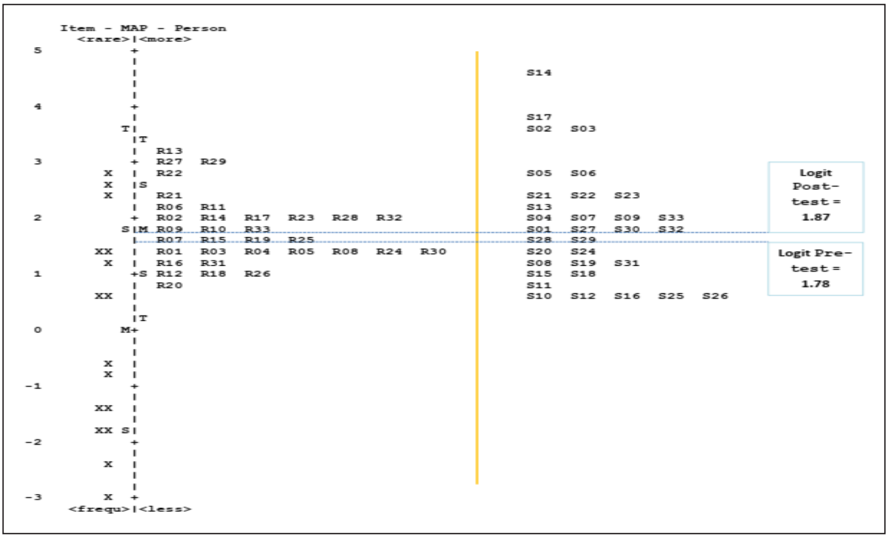


Figure 6. Stacking Wright map results from attitude questionnaire towards STS

However, it differed from the questionnaire results of student attitudes towards STEM-PjBL. The mean results of LVP of student attitude towards STEM-PjBL were +0.49 for the pre-test and +0.44 for the post-test, so the difference was –0.05. Therefore, the intervention tended to have a negative effect on students' attitudes toward STEM-PjBL. It was possible since the intervention process took a long time. Related to that, several studies have stated that one of the limitations of implementing STEM-PjBL is that it takes a long time, so students may experience a decrease in attitudes at the end of learning (Connor et al., 2015; Huri & Karpudewan, 2019; Rezayat & Sheu, 2020). Stacking Wright map results from the attitude questionnaire towards STEM-PjBL are presented in Figure 7.

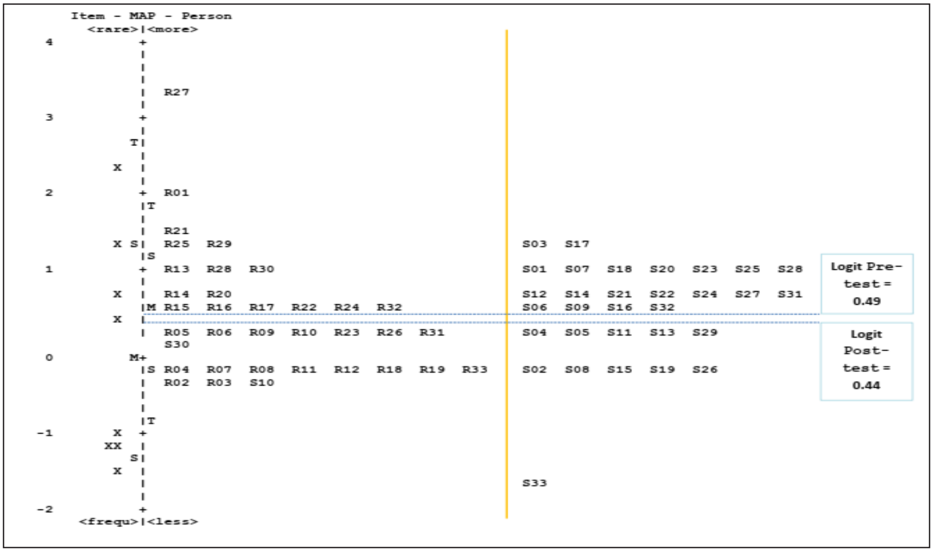


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Figure 7. Stacking Wright map results from attitude questionnaire towards STEM-PjBL

Figure 7 displays the pre-test (R) and post-test (S) results of LVP on student attitudes toward STEM-PjBL. For example, the LVP of the student's attitude towards STEM-PjBL from R7 during the pre-test was -0.09 and an LVP S7 of +0.97 after the intervention. It suggests an increase in logit, meaning that the student experienced a change in a positive attitude towards STEM-PjBL. Unlike the case with R27, with an LVP of +3.41 during the pre-test, S27 had an LVP of +0.69 after the intervention. It demonstrates that the student experienced a decrease in LVP, which could be said to have negative attitudes towards STEM-PjBL.

Moreover, stacking techniques provide information about "who has changed," whereas the racking technique offers information about "what has changed" (Laliyo et al., 2022). The student attitudes towards STS and STEM-PjBL questionnaire racking results are presented in Table 10.

Table 10. The racking results of student attitudes towards STS and STEM-PjBL questionnaire

	Pre-test mean	Post-test mean	Difference	Pre-test mean	Post-test mean	Difference	*P**
	High (+)	High (+)		Low (–)	Low (–)		
STS	–1.57	–1.56	+0.01	+1.54	+1.59	+0.05	<0.01
STEM-PjBL	–1.04	–1.21	–0.17	+1.03	+1.23	0.2	<0.01

The racking analysis results in Table 10 revealed that the mean LVI pre-test on the positive criteria of student attitudes towards STEM-PjBL was –1.04. In the post-test situation, the positive criteria of difficulty were reduced to –1.21, resulting in a difference of –0.17 logit scale. At the same time, the negative criteria had a difference, which was a +0.2-logit scale. It can be said that the difficulty of the questions increased during the post-test, indicating a decrease in the positive attitude of the students towards STEM-PjBL. Meanwhile, the STS questionnaire showed that the mean LVI pre-test on the high criteria was –1.57. In the post-test situation, the high criteria had decreased to –1.56, resulting in a difference of +0.01 logit scale. Simultaneously, the low criteria had a difference of +0.05 logit scale. It can be said that more students had high criteria for STS after the intervention compared to students with low criteria for STS.

Post-Test Results

The post-test instrument was constructed based on the STS indicators in a simple AAS development context. The measurements using this instrument were analysed using descriptive statistics to determine the data distribution and the proportion of mastery of students' systems thinking skills in each indicator. Descriptive statistical data are presented in Table 11, while the proportion of student mastery data is shown in Figure 8**.**

Table 11. Descriptive statistics post-test results

Descriptive stat	STS indicators							
	1	2	3	4	5	6	7	8
Mean	3.03	2.64	3.18	2.09	2.30	3.00	2.79	3.33
Standard error	0.17	0.14	0.18	0.12	0.13	0.16	0.11	0.14
Median	3.00	2.00	4.00	2.00	2.00	3.00	3.00	4.00
Mode	4.00	2.00	4.00	2.00	2.00	4.00	3.00	4.00
Standard deviation	0.95	0.82	1.01	0.68	0.77	0.94	0.65	0.82
Sample variance	0.91	0.68	1.03	0.46	0.59	0.88	0.42	0.67
Sum	100	87	105	69	76	99	92	110

Figure 8. The proportion of STS indicators mastery

Based on data from Table 11 and Figure 8, systems thinking skills indicators 1, 3, 7 and 8 had a relatively high proportion of students' mastery, while indicators 2, 4 and 5 tended to produce low results. The indicators are:

(1) Students acquire the ability to identify the AAS system components and processes.
(2) Students can identify relationships and characteristics between components in the AAS system.
(3) Students learn to organise the composition of alternative components used in the simple AAS construction process in a related framework.

(4) Students develop the ability to generalise from various alternative solutions to replace components in simple AAS systems.
(5) Students develop the ability to identify dynamic relationships in the constituent components of the AAS system and with the systems of daily life.
(6) Students understand the hidden dimensions they are unaware of from the simple AAS system.
(7) Students develop the ability to understand the nature of the cycle in the AAS system development and the context of daily life related to the AAS system.
(8) Students learn to think temporally and retrospectively, collaborate, and make predictions of opportunities to realise their simple AAS design into a prototype.

Interview Results

Table 12 presented the interview results from five students who had been selected previously. The results shown were analysed for the similarity of answers between the students interviewed.

Table 12. Interview results

Questions	The student's representative answer
(1) In your opinion, what is the difference between the simple AAS laboratory practicum and the laboratory practicum on the previous instrument?	**Student B:** This AAS practicum method, which is a project, develops my way of thinking, understanding, and teamwork skills. I understand better how AAS works because I was challenged to think and provide solutions to develop simple AAS tools. **Student A:** I like the current method of AAS practicum, although it is enough to make me dizzy since the revision comments are quite complicated. Still, I can understand this AAS practicum very well because I understand every detail of the component functions. I hope my group and I can visualise the AAS design.
(2) How did the model implement in a simple AAS practicum with the project help you to understand the AAS instrument in more depth?	**Student C:** In this AAS practicum method, I was asked to develop a simple AAS tool. To develop AAS tools, I need to understand how they work, the characteristics of components, and the processes that occur in AAS instruments. Therefore, I became more understanding as I needed to find and understand this information. **Student D:** To design a simple AAS tool, it is necessary to have in-depth knowledge of every detail, function, and characteristic of its components, which is very helpful in understanding the AAS instrument in-depth.

(Continue on next page)

Table 12 (continued)

Questions	The student's representative answer
(3) In your opinion, which part of the project contributed to training knowledge and skills in the STEM field?	**Student A:** From learning to design and even considering how the tool can work well, it indicates that we all have to have skills like mechanical engineering students; even though it feels complicated because of this, the group makes this job more manageable. Considering the tools' durability and smoothness, skills in designing must be developed. **Student C:** This project connects and requires my science, technology, engineering, and mathematics knowledge and skills. This project asked me to develop a simple AAS tool. Science skills are needed when designing tools. Meanwhile, engineering skills, as well as technology, are implemented during implementation. However, the four things are interrelated and complement one another.
(4) In your opinion, how does the given project train you to think holistically?	**Student C:** The whole project section trained me to think holistically and systematically. After being given the problem of constructing a simple AAS design, I had to be able to strategise and think about how each component in the design could meet its objectives and form an AAS instrument that could function properly. In addition, some criteria, such as simple and portable, challenged me to think deeper. **Student E:** The project requires us to always think about the risks or impacts when incorporating new components. Regarding the effect that occurs, of course, I extend thoroughly from one component to another and the analysis results. This project helps me think about the relationship between components holistically and systematically.
(5) How does the applied model affect your perspective on the AAS instrument?	**Student D:** Better understand that AAS influences technological advances in health, industry, and others. **Student E:** This practicum made me more knowledgeable about AAS, especially its contribution to the environment and daily life. Because the previous practicum using the instruments that had been provided did not make me aware of their contribution to the environment and everyday life, I assumed that these instruments could not be understood. However, this contextual practicum can change my assumption.

In the first question, the answers from students indicated that the interventions carried out differed from the previous laboratory activities. In this case, during the COVID-19 pandemic, lectures and laboratory activities were conducted online. It included the Uv-Vis practicum conducted before the intervention. Student A, on the first question, emphasised the reflections carried out during the intervention. This reflection related to how the intervention provided feedback and opportunities for students to reflect on what they had proposed to realise the project. It aligns with the research results mentioning the lack of reflection during online learning and practicum. Therefore, reflection becomes an essential part of laboratory activities both online and online (Kidd & Murray, 2020).

In the second and third questions, students' answers suggested that the interventions made them understand the parts of AAS more deeply. It was because they had to carry out engineering projects to find alternative replacements for the main components in AAS. It is in accordance with the post-test results, showing that the following systems thinking skills indicators had a higher proportion of mastery: (1) students acquire the ability to identify the AAS system components and processes, and (3) students learn to organise the composition of alternative components used in the simple AAS construction process in a related framework.

In the fourth and fifth questions, students expressed that they could think holistically and related learning or laboratory activities to various problems related to daily life. This result is also consistent with the post-test results, showing that the following systems thinking indicator tended to produce high proportions of mastery: (7) students develop the ability to understand the nature of the cycle in the AAS system development and the context of daily life related to the AAS system. Before the intervention, students focused on the AAS components and functions; students had not been able to see the relationship between the AAS instrument and various problems in everyday life. However, after the intervention, students might even consider the benefits of using AAS daily. The AAS practicum's concept, which initially did not impact their social life, turned into an instrument that contributed to solving various problems in their daily lives. The feedback results on the intervention also provided data on students' impressions of the simple AAS lab activity carried out in their class.

Furthermore, systems thinking emphasises the interdependence between components. In the context of chemistry, systems thinking considers not only reactions and processes but also students to take into account where chemical materials/tools come from, how these materials/tools are utilized, and the impact of the use of chemical materials/tools for life (Mahaffy et al., 2019; Mahaffy, Brush, et al., 2018). In the intervention of laboratory-based pedagogy, students were also required to think about the contribution of a simple AAS prototype to the daily life system. It aimed to associate learning content with the context of everyday life in accordance with the assessment of skills and systems thinking approaches (Talanquer, 2019; York et al., 2019).

DISCUSSION

During the pandemic, the chemistry separation and measurement practicum that used a spectrophotometer was carried out online by displaying videos from YouTube and providing secondary data. Students did not have the opportunity to see the spectrophotometer instrument in detail. In addition, students could not directly practice sample testing with spectrophotometer instruments. It made them have a limited understanding of the spectrophotometer instrument components, basic principles, the instrument operation, and reading of the spectrophotometer output (Shidiq et al., 2020b, 2020c, 2021a).

By doing simple AAS instrument construction through STEM-PjBL, students were given the experience of learning in more detail. Before constructing a simple AAS prototype, students needed to know the AAS instruments' functions, workings, and basic principles. It corroborates various studies on developing other simple spectrophotometer instruments (Moraes et al., 2014; Wigton et al., 2011). Moreover, constructing this simple spectrophotometer instrument becomes a solution for teachers to teach spectrometry at the university and high school levels; even research conducted by Lafratta (Lafratta et al., 2013) has proven that junior high school students could understand the function of spectrometry using his homemade tools.

Furthermore, the STEM education approach emphasizes a new way of teaching and learning that focuses on direct inquiry and open exploration (Katehi et a., 2009). This approach also allows learners with diverse interests, abilities and experiences to develop the skills they will need in the 21st century (Wahono & Chang, 2019). Nevertheless, STEM approaches involving many skills and integration between science, technology, engineering and mathematics often adversely affect students (Chaiwongsa et al., 2019). In this study, students' negative attitudes towards implementing laboratory activities with STEM-PjBL were also generated. Still, many studies have reported the effect of positive attitudes toward STEM approaches, even on career determination in STEM fields (Beier et al., 2019; Khanlari, 2014; Pinasa & Srisook, 2019; Rezayat & Sheu, 2020).

Various factors are thought to cause students' negative attitudes toward the interventions. The primary factor is the length of time the intervention was carried out. It was also exacerbated by the lockdown status in the city, requiring intervention activities to be delayed by several weeks. Another factor is that students were already familiar with lab instructions like cookbooks. Laboratory activity guides with "cookbooks" can teach some laboratory techniques or serve as visual aids for concepts already learned, most of which are ineffective tools for teaching science concepts. Therefore, cookbook laboratory activities can function well as illustrations of ideas that have been studied and understood but are unlikely to lead to new conceptual learning (Acar Sesen & Tarhan, 2013; Wu & Hsieh, 2006). In many science school programs, laboratories have been used in the "cookbooks" mode to verify scientific facts, but they are not utilised to promote science process skills to investigate natural phenomena (Kilinc, 2007).

It suggests that laboratory activities are a viable platform for integrating the four STEM disciplines since STEM integration requires cognitive challenges to solve real-world problems. Meaningful learning in the laboratory will only occur if students are given sufficient time and opportunities for interaction and reflection to start discussions (Acar Sesen & Tarhan, 2013). Further research on the influence of science laboratory instruction on the development of students' conceptual understanding suggests that when laboratory experience is integrated with the learning experience, combining and manipulating ideas, not only materials and procedures, could improve their knowledge of science concepts (Acar Sesen & Tarhan, 2013; Tarhan & Sesen, 2010). In the implementation, a simple STEM-PjBL AAS practicum with the *Engineering Design Processes* stage provides an opportunity for students to look for various alternative data analysis methods, manipulate tools, and develop ideas to relate practicum as an alternative way to solve real-world problems. Thus, a simple AAS practicum with STEM-PjBL makes the practicum more meaningful if done correctly.

In this study, the intervention was carried out not only to construct a simple AAS prototype but also to introduce systems thinking skills to students. When utilised appropriately, some skills associated with systems thinking can give students a deeper insight into chemistry.

The system has at least three characteristics: component/part, the interconnection between components, and purpose (Pazicni & Flynn, 2019). The results of this study are in line with this statement. Indicators related to the identification of components, prediction, and cyclic systems were moderately significant indicators. In addition, it also corresponds to the hierarchical theory of systems thinking, emphasizing the relationship between components in the system (Assaraf & Orion, 2005; Huang et al., 2015; Talanquer, 2019).

Moreover, four main dimensions jointly build the system thinking construction in this study. First is an understanding of the system's structure, including the components of a system and the interrelationships between components (Arnold & Wade, 2015; Chiu et al., 2019). Secondly, understanding the behaviour of complex systems includes the dynamic characteristics that arise and the causation of the components in a system. It allows the study of how components behave and generate patterns or impact the system (Chiu et al., 2019). The third is the understanding of systems at different scales, including macroscopic (phenomena) and microscopic (structural) representations, symbols of elements in a system, generalisation of components, and understanding of hidden dimensions of the system (Arnold & Wade, 2015; Chiu et al., 2019). The fourth is the understanding to connect chemical content to the context of society, technology, economy, and environment, including the interrelationships between society, chemistry, innovation and technology from the view of global issues regarding sustainability, environmental protection, and the application of chemistry in the industry (Flynn et al., 2019; Mammino, 2019).

The application of systems thinking can further facilitate students' more holistic and comprehensive perspectives that enable them to understand the theory and practice of chemistry better, appreciate chemistry in relevant contexts, and develop the capacity to explore complex chemical relationships, environmental constraints and societal needs. To achieve this, chemistry education needs a method to help frame and manage complexity so students can develop their capacities optimally (Constable et al., 2019). Alternatives that can be done are project-based, problem-based and case-based learning (Mahaffy, Krief, et al., 2018). It has been accommodated by the intervention in this study, linking STEM-PjBL to construct a simple AAS prototype with problems related to daily life. In addition, it is also reinforced by research stating that introducing green chemistry with laboratory-based pedagogy is essential to develop environmental literacy and proving that environmental issues can be integrated into learning (Karpudewan et al., 2009). It can also encourage students to connect the chemical concepts they learn in class with economic, socio-political, and engineering systems. Besides, this framework requires students to apply their knowledge of science and society to create meaningful ways to learn and practice science holistically (Karpudewan et al., 2012a; (Karpudewan, Roth, & Ismail, 2015).

Various studies have also shown promising results from the integration of laboratory-based pedagogy with environmental issues (green chemistry), such as increasing self-determined motivation (Karpudewan et al., 2012a), increasing knowledge and attitudes of elementary school students towards global warming (Karpudewan et al., 2015), being able to bring about shifts in value orientations that emphasize environmental protection (Karpudewan et al., 2012b), students better assimilate the subject and become more literate in science (Kolopajlo, 2017) and helped students to obtain a different perspective in terms of environmental awareness (Günter et al., 2017).

CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

This research has successfully implemented a hybrid laboratory pedagogy to construct a simple spectrophotometer with STEM-PjBL to introduce system thinking skills. In addition, students have successfully developed designs and constructed simple AAS prototypes, which are relatively simple, inexpensive and portable. Comparing these characteristics, the resulting simple AAS prototype can be used as a simple learning medium for high school students.

As a practical implication, this intervention offered an alternative hybrid laboratory-based pedagogy model to combine mind-on and hands-on activities in a structured way. It aligns with research that combining mind-on and hands-on activities during remote laboratory activities is quite a significant result (Scruggs et al., 2020; Works et al., 2020). This positive result is expected to be a reference for implementing laboratory-based pedagogy to introduce system thinking skills. Besides, there are similarities and differences in the several innovative pedagogies developed at the (g)local level. This research provides space for students to collaborate not only with their peers but also with the people around them, according to their expertise, an essential source of information to gain holistic knowledge.

Nevertheless, it must be clearly stated that implementing hybrid laboratory-based pedagogy has drawbacks. During the hybrid laboratory activity process, student discussions to obtain alternative solutions for project completion have not been optimally monitored. It is in line with several studies that asserted that laboratory activities during a pandemic are challenging to facilitate students to have laboratory knowledge and skills (Gravano et al., 2021; Kidd & Murray, 2020; Marvin, 2020). Additionally, constructing a simple AAS prototype over a relatively long time is also difficult in this research. It took not only student consent to be involved but also a commitment to complete the project, which is another challenge to implement this type of pedagogy.

Moreover, it is a small-scale study; hence, the findings are not generalisable. This research was conducted by involving only one class, with one group pre-post design being the main limitation of this study. The absence of a control class made the justification of the results of this study weak. In addition, the too-long intervention time was also a significant factor in students' negative attitudes toward the STEM-PjBL implementation. Accordingly, control classes and shorter implementation times are required to get consistent results. Another limitation is that the repeatability indicator of the simple AAS developed had not been well tested. Therefore, it can be recommended for further research to use more classes with a more measured time, perform more consistent iterative testing, and apply them to a variety of other laboratory instruments.

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APPENDICES

Appendix A

Questionnaire of student attitudes towards STEM-PjBL

No	Type	Statements
1	-	AAS practicum should not be integrated with the technology field because there is no relationship between these two fields.
	+	Technology development depends on the advancement of science (and vice versa); therefore, AAS practicum must be taught integrated with technological progress.
2	-	Combining the AAS practicum program with engineering technology is burdensome since it will increase the burden on the practicum with engineering technology.
	+	The combination of the AAS practicum program with engineering technology is interesting as it allows me to see how the subject matter relates to the context of its application to everyday life.
3	-	The AAS practicum combined with the technology and engineering program was challenging for me because I had to deal with several subjects and skills at once.
	+	The AAS practicum program, combined with technology and engineering, helped me to understand the material better as it was presented from a different perspective.
4	-	The AAS practicum program combined with technology and engineering leads to the shallowing of students' understanding of chemistry, technology, and engineering.
	+	The combination of AAS practicum programs combined with technology and engineering leads to a deep understanding of chemical science and technology applications.

The questionnaire on student attitudes toward systems thinking skills

No	Type	Statements	STS Indicators
1	High	When I am involved in a simple AAS practicum and engineering project, it is crucial for me to understand the overall detailed picture of the components and their processes.	Students acquire the ability to identify the AAS system components and processes.
	Low	When I am involved in a simple AAS practicum and engineering project, it is crucial for me to know the general description of the final product produced.	
2	High	When I am responsible for developing specific components that are part of a simple AAS practicum and engineering project, it is crucial for me to identify the relationship between the components that I am responsible for with other product components.	Students can identify relationships and characteristics between components in the AAS system.
	Low	When I am responsible for developing specific components that are part of a simple AAS practicum and engineering project, it is crucial that I focus on my tasks only.	

3	High	While I am responsible for the development of specific components that are part of a simple AAS practicum and engineering project, it is crucial for me to understand how they affect and integrate into the product as a whole.	Students develop the ability to identify dynamic relationships in the constituent components of the AAS system and with the systems of daily life.
	Low	When I am given the task of being responsible for one particular component that is part of a simple AAS practicum and engineering project, it is crucial for me to know the performance results of the components I am working on.	
4	High	When I engage in simple AAS practicum and engineering, it is crucial for me to select and determine the most promising component alternatives for the final product produced.	Students learn to organize the composition of alternative components used in the simple AAS construction process in a related framework.
	Low	When I am involved in simple AAS practicum and engineering projects, it is crucial for me to choose the alternative solution that is easiest for me.	
5	High	When I am responsible for working on simple AAS practicum and engineering projects, I consider the development process cycle and the contribution of AAS products to the system of daily life.	Students develop the ability to understand the nature of the cycle in the AAS system development and the context of daily life related to the AAS system.
	Low	When I am responsible for working on simple AAS practicum and engineering projects, I focus on the final product produced.	
6	High	When drawing conclusions or decisions from a problem in a simple AAS practicum and engineering project, I tend to pay attention to the internal and external components that affect the product to be produced.	Students develop the ability to generalize from various alternative solutions to replace components in simple AAS systems.
	Low	When it comes to making conclusions or decisions from a problem that exists in a simple AAS practicum and engineering project, I tend to focus on the internal factors that are most influential.	
7	High	When completing simple AAS practicum and engineering projects, I think it is essential to identify problems and patterns not observed by developers based on other people's points of view.	Students understand the hidden dimensions they are unaware of from the simple AAS system.
	Low	In completing simple AAS practicum and engineering projects, I think identifying hidden problems and patterns based on my point of view is essential.	
8	High	To produce a good product from a simple AAS practicum and engineering project, I think it is necessary to identify problems that may occur and the function of each component in the product so that it can be used as a reference for product improvement.	Students learn to think temporally and retrospectively, collaborate, and make predictions of opportunities to realize their simple AAS design into a prototype.
	Low	In the final stage of a simple AAS practicum and engineering project, I think the most important focus is on the excellence of the resulting product.	

Appendix B

Specifications for tools used on lamp sets:

1. Specification of Philips SON-T Sodium Lamp 70 Watt
   a. Base Head : E27
   b. Color Code : 220
   c. Color Temperature : 2,200K
   d. Lumen : 6,000 lm
   e. Endurance : up to 28,000 days
   f. Dimensions : 36 mm x 156 mm
2. Specification of Philips HID Ballast 70-Watt Sodium Lamp
   a. Input Voltage : 220 V
   b. Input Frequency : 50 Hz
   c. Connector Type : Screw
   d. 1 : 0.40
   e. Mainline : 0.98A
3. Philips SN 57 Ignitor Specifications
   a. Inlet Voltage : 220 V – 240 V
   b. Input Frequency : 50 Hz – 60 Hz
   c. Ignitor Voltage (Max.) : 2.5 kV
   d. Ignitor Voltage (Min.) : 1.8 kV
   e. Response Voltage : 190 V
4. Philips 30 uF Capacitor Specifications
   a. Input Voltage : 250 V
   b. Input Frequency : 50/60 Hz
   c. Resistance : 1.2MΩ

Specifications for the tool used in the atomization set:

1. Burner specifications
   a. Material: Stainless steel, copper, and aluminum
2. Specification of Nebulizer (Ultrasonic Nebulizer MY-520 A)
   a. Ultrasonic Frequency: 2.0 MHz
   b. Particle Size: 0.5-5 microns
   c. Cup Capacity: 10 mL
   d. Vessel Capacity: 25 mL
   e. Atomization Volume 0.375mL/min: 20 min (auto time)
   f. Atomization Volume 0.5mL/min: 10 min (auto time)
   g. Operating Voltage: DC12V
3. Portable gas specifications
   a. Gas Contents: Butane
   b. Resulting Temperature Estimate: 1970°C
   c. Net: 235 grams

Specifications of the lux meter used:

1. Lux meter specifications (Model: LX1010B)
   a. Display: 18mm (0.7”) LCD
   b. Range: 0-50,000 Lux. 3 Range
   c. Over-input: Indication of “ I “
   d. Sampling Time : 0.4 seconds
   e. Operating Temperature : 0° to 50°C
   f. Operating Humidity: less than 80% R.H.
   g. Dimensions: 118 × 70 × 29 mm (4.6 × 2.7 × 1.1 inch)
   h. Weight : 200g (battery included)
   i. Power Supply: 006P DC9V battery Current consumption of about 2mA