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Developing Worksheets Using Engineering Design Process to Promote Sustainable Development Goals for Pre-service Physics Teacher

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Abstract

This research aims to design a worksheet using the Engineering Design Process (EDP) model to promote Sustainable Development Goals (SDGs) that are appropriate for pre-service physics teachers. The specific objectives of this study are to describe the validity of the worksheet and explore the pre-service physics teacher's response to the worksheet. The research design is research and development (R&D) with a model of analysis, design, development, implementation, and evaluation (ADDIE). The participants in this study were 45 pre-service science teachers. The research instruments are the worksheet validation sheet and the response questionnaire. The results show that the worksheet is categorized as very feasible. In addition, based on the pre-service physics teachers' responses, the worksheet is in a good category. It can be concluded that the developed worksheet using the EDP model is appropriate for learning.

Keywords: Engineering Design Process; Pre-service Physics Teacher; SDGs

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INTRODUCTION

Among the seventeen Sustainable Development Goals (SDGs), access to safe water is the most fundamental requirement for human health and well-being. Rapid population growth, urbanization, and rising water requirements from agriculture, industry, and energy sources are driving an increase in water demand (United Nations, 2017). However, Indonesia's water quality faces a number of obstacles, particularly those resulting from human activity (Handayani et al., 2019; Sholihah et al., 2020; Subagiyo et al., 2019). Therefore, it is essential to support initiatives that shape the human understanding of water.

Science teachers are expected to educate students more about the environment. For the pre-service teacher level, water treatment activity is also an interesting topic to be explored (Oyewo et al., 2022). Water pollution is still one of

the crucial issues in many big cities in developing countries, such as Indonesia (Ferronato & Torretta, 2019; Suwarno et al., 2014; Yu et al., 2015). A contextual problem, in this case, water sanitation problems, may provide some opportunities for engaging students and motivating them in learning, one of which is in an integrated science course. Therefore, water problems are a suitable topic for inclusion in integrated science courses as a contextual problem.

STEM education in science programs have increased in popularity recently. (Dewi & Jauhariyah, 2021; Hartini et al., 2020; Mutakinati et al., 2018; Retnowati, & Subanti, 2020). Sulaeman et al., 2022). STEM has the most beneficial advantages for enhancing student learning outcomes. Adjusting STEM learning to the curriculum and the need for effective time management are the most significant challenges in STEM education (Baharin et al., 2018; Norlaili et al., 2022; Sithole et al., 2017). The engineering design process (EDP) is one of the most extensively used instructional models that could complement the STEM education approach (Putra et al., 2023a; Sulaeman et al., 2020; Wind et al., 2019).

Developing worksheets for students using STEM and EDP has become a focus of many researchers (Hartini et al., 2020; Putra et al., 2023b).However, worksheets for pre-service science instructors are infrequent. Our research aims to develop suitable EDP-based worksheets on the topic of water for pre-service science teachers.

METHOD

The Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model was used to develop the worksheet in this study. The development flowchart of this study was depicted in Figure 1. In the analysis phase, the SDGs, the science curriculum for high school, and the pre-service physics teacher curriculum were analyzed to determine the content of the worksheet that would be developed. Following the result of the analysis phase, the design of the student worksheets consisted of water turbidity level measurement and water filtration. In the development phase, validation was conducted, and the worksheet was revised based on the validation results by two experts in EDP and science education. In the implementation phase, product testing was conducted in the pre-service physics teacher program for 45 pre-service teachers, also measuring the practicality and effectiveness of the worksheet. In the evaluation stage, the advantages and disadvantages of the student worksheet and possible improvements were discussed. ADDIE's stages are shown in Figure 1.

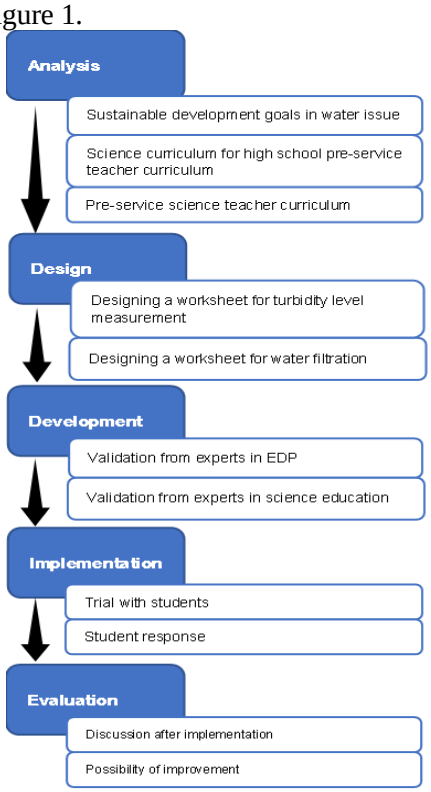

Figure 1 ADDIE Stages

The worksheet developed in this study was implemented for 45 pre-service physics teachers at a public university in Indonesia. After the implementation, the participants filled out a questionnaire related to their experience using the worksheet. Worksheet validation was

measured by giving validation sheets to two experts. On the other hand, the worksheet was validated using an instrument adapted from Melati et al. (2019). The instrument contained five aspects of validity, as listed in Table 1.

Table 1 Aspects of worksheet validity

Aspect	Number of Items
Presentation	5
Subject Matter	7
Content	5
STEM EDP	4
Linguistic	7

The student response to the worksheet was investigated using a questionnaire adapted from Ekantini & Wilujeng (2018). The aspects contained in this questionnaire can be seen in Table 2.

Table 2 Aspects of student response

Aspect	Indicator
Figure Display	The figures are clear and interesting
Student Worksheets Display	The worksheet display is interesting
Figure, Tables, and Questions Layout	The layout of figures, tables, and questions are displayed clearly and appealingly
Title, Command, Figure, Table, and Question Display	Titles, commands, drawings, tables, and questions are clearly displayed
Language Usage	The language used in the worksheets is clear and easy to understand
Font Size	Font size is appropriate
Clarity of Information	The information is presented clearly

This questionnaire uses Likert Scale with five scales presented in Table 3.

Table 3 Validity assessment

Criteria	Score
Very Good	5
Good	4
Fair	3
Poor	2
Very Poor	1

The validity and student response results were calculated using Eq. (1).

$$P = \frac{TSe}{TSh} \times 100\% \quad (1)$$

Where P is the validity percentage, TSe is the total score for each aspect, and TSh is the highest score for each aspect.

The calculated percentage of worksheet validity was compared with the interpretation category adapted from Rizqiyyah & Novita (2022), as shown in Table 4.

Table 4 Categories of validation result

Percentage (%)	Category
81 - 100	Very Feasible
61 - 80	Feasible
41 - 60	Fairly Feasible
21 - 40	Less Feasible
0 - 20	Not Feasible

The criteria for the student responses on the worksheet are shown in Table 5.

Table 5 Categories of student response

Percentage (%)	Category
81 - 100	Very Good
61 - 80	Good
41 - 60	Fair
21 - 40	Poor
0 - 20	Very Poor

RESULT AND DISCUSSION

Analysis phase

Analysis was the first phase of the development procedure. The researchers analyzed the Sustainable Development Goals (SDGs), the Indonesian science curriculum, and the curriculum for pre-service science teachers. In this phase, the global issues outlined in the SDGs became the guiding document (United Nations, 2015). Although the objectives are essential for the future, university students have a limited understanding of these issues (Krishna et al., 2022). Among the 17 Sustainable Development Goals are the following: 1) no poverty; 2) zero hunger; 3) excellent health and well-being; 4) quality education; and 5) gender equality. 6) clean water and sanitation; 7) affordable and clean energy; 8) decent work and economic growth; 9) industry,

innovation, and infrastructure; 10) reduced inequalities; 11) sustainable cities and communities; 12) responsible consumption and production; 13) climate action; 14) life below water; 15) life on land; and 17) partnerships for the goals. These environmental concerns are highly relevant to pre-service science teachers. Therefore, water would be a focus of the development process.

In relation to environmental issues, particularly water problems, the high school science curriculum includes a topic such as matter property. Courses within the pre-service science curriculum are categorized according to the program learning outcome. The discipline with the closest relation is integrated science.

Design phase

In this study, the worksheet of STEM activity was developed using EDP. The worksheet integrated science in scattering, absorption, and light reflection via the development of water turbidity level measurement and particle transport and attachment through filtration. Technology, in this case, the smartphone, was used in developing the turbidity level measurement tool. Technology was also used to browse information about the mechanism of water turbidity level measurement and water filtration. Engineering was obtained via the EDP to plan and design the measurement tool for water turbidity level and straightforward water filtration with a minimum cost.

Additionally, mathematics was applied to plot graphs, calculate the water debit, and calculate the cost. In engineering, the EDP is frequently used to solve engineering problems. Engineers could design devices and processes optimally suited to a specific purpose through EDP. Table 6 presents the procedure of EDP for the proposed worksheet (Khamhaengpol et al., 2021).

Table 6 EDP procedure of the developed STEM worksheet

EDP	The proposed STEM activity
Define	Identifying the needs related to water issues and their constraints.
Learn	Literature studying water turbidity and filtration and looking for solution methods for water issues.
Plan	- Designing and sketching water turbidity level measurement tools and water filtration. - Developing water turbidity level measurement tools and water filtration.
Try	Testing and evaluating developed water turbidity level measurement tools and water filtration.
Test	Redesigning developed water turbidity level measurement tool and water filtration as needed.
Decide	Presenting their designs and successes with the whole group.

The developed STEM worksheet consisted of two primary sections. Using a smartphone, the first step involved the creation of a device for measuring water turbidity. Figure 2 illustrates an example of the worksheet. To convince students of the necessity of measuring the turbidity of water, the detrimental effects of dirty water on living organisms were described. Students were encouraged to devise smartphone-based turbidity measuring devices. The equipment should be able to measure water level turbidity and be user-friendly, precise, resilient, low-cost, and eco-friendly. The assignments were assigned to groups of students who were given a week to complete them. Students then had a week to consider their design and make adjustments. At the end of the activity, students were able to understand the

mechanism of water turbidity measurement instruments based on scattering, absorption, and refraction of light. The worksheet display is shown in Figure 2.

Figure 2 Worksheet display

Students were instructed to develop a rudimentary water filtration system for reducing water turbidity in the second section. Through a literature review, students were encouraged to consider suitable materials for water filtration. Students created water filtration systems that met the following criteria: durability, ability to reduce water turbidity and generate a steady water flow, low cost, and environmental friendliness. The developed water filtration system was evaluated with artificially contaminated water and water samples from three distinct sources. As the initial assignment, each group was given two weeks to complete this endeavor. In this section, students understood the mechanism of particulate transport and attachment via filtration. This worksheet's project was founded on the EDP.

Regarding the SDGs, the worksheet was also completed with the connection to the SDGs. This part was made to inform students about what parts of the SDGs were intended to be achieved by the projects on the worksheet. The SDGs connected to this worksheet were goals 3, 6, and 13, which related to good health and well-being, clean water and sanitation, and climate action, respectively.

Development phase

Validity is one of the criteria for determining the quality of a developed product (Md Ghazali, 2016). In this phase, we conducted validation of the developed worksheet by two validators. Validator 1 was an expert in STEM-EDP, and validator 2 was a lecturer in the Science Education Department. The validation was analyzed based on five aspects: presentation, subject matter, content, STEM EDP, and linguistics. The result of validation by both experts in more detail can be seen in Table 7.

Table 7 Validation results of the worksheet by expert

No	Validity Aspect	Percentage (%)	Category
1	Presentation	90	Very Feasible
2	Subject matter	87	Very Feasible
3	Layout	94	Very Feasible
4	STEM EDP	90	Very Feasible
5	Linguistic	90	Very Feasible
	Average	90	Very Feasible

According to Table 7, the average result of validation by experts was 90%. The developed worksheet can be classified as very feasible and suitable for use as a learning support tool. The content aspect scored the highest average percentage. In this case, it was assumed that the product was adequately arranged in terms of text, color, and picture (Suliyanah et al., 2020). In other terms, this product can motivate pre-service physics teachers throughout their education. whereas, the subject matter obtains the lowest percentage score among the five validation criteria. Therefore, this product must be enhanced in terms of its material and technological developments.

The validity criteria for the presentation were based on the instructions for using the worksheet that directs learning activities. Table 8 shows the validation of the presentation aspect. The worksheet adapted to the STEM model feasibly, as seen from the average validation result score of 5. The structure and guidelines of worksheets, the suitability of activities with a scientific approach, and step-by-step instructions are good categories. According to these results, the worksheet was presented adequately to support students in understanding water purification in a hands-on manner.

Table 8 The validation presentation aspect

Statement	Average
The structure of worksheets relates to one another	4.5
The guidelines on the worksheets are clear and easy to understand	4.5
Learning activities following the scientific approach	4.5
Worksheets presentation adapted to the STEM model	5.0
Step-by-step instructions according to the actual stage	4.0

Table 9 presents the following aspects of validation subject matter. As demonstrated by the maximum score, validators concurred that the worksheet encourages students to acquire scientific knowledge of water filtration. The validation results indicate that the developed worksheet could help instructors with STEM education that is based on scientific truths and technological advances. The worksheet utilized problems to facilitate learning and relate the subject matter to real-world situations.

Table 9 The validation content aspect

Statement	Average
Worksheets are presented following the scientific truth	4.5
The worksheet is presented according to the depth of the material	4.0
The presentation of the problems given follows the facts of everyday life	4.0

Statement	Average
Activities in worksheet are related to life	4.5
Activities in worksheets encourage students to study scientifically	5.0
The presentation of worksheets follows technological developments	4.5
Work steps on worksheets can guide prospective teachers	4.0

The validation of the content aspect is presented in Table 9. The content aspect of the worksheet included several things, such as the combination of letters, layout, display, color, and interactiveness to attract students' attention. The layout, subtitles, pictures, and color pattern in this worksheet were placed appropriately based on the validation scores. The worksheet contents were not excessive and made it easy for students to understand.

Table 10 The validation layout aspect

Statement	Average
The letters used are clear and easy to read	4.5
Proportional worksheets layout	5.0
The worksheets display design is attractive	4.5
The color selection is not excessive	5.0
Worksheets provide interaction in the form of stimulus	4.5

Table 11 shows the STEM EDP validation aspects listed below. Validators concurred that the worksheet contains STEM elements, and validation results indicate that the developed worksheets covered EDP procedures.

Table 11 The validation STEM EDP aspect

Statement	Average
The relationship between the material and science in general	4
Contained the applications in the field of technology	4.5
Contained engineering design process	5
The use of mathematics in presenting the material	4.5

In Table 12 are described the linguistic aspects of validation. Validators concurred that the worksheet made use of appropriate language, primarily in accordance with Indonesian language standards. The language on the worksheet was appropriate for pre-service teachers.

Table 12 The validation of linguistic aspect

Statement	Average
Following the language rules	4.5
The language used is communicative	4.5
The language used is easy to understand and not ambiguous	4.0
The information on worksheets is clear	4.0
Consistency in the use of terms	5.0
Consistency in the use of symbols	4.5
Foreign words following a formal dictionary	5.0

Implementation phase

These were the student responses to the produced worksheets. In detail, it can be seen in Table 13.

Table 13 The student's response result

Aspect	Percentage
Image Display	84%
Worksheets Display	87%
Image, Tables, and Questions Layout	83%
Title, Command, Picture, Table, and Question Display	84%
Language	81%
Font Size	85%
Clarity of Information	85%

Evaluation phase

To improve the quality of the learning process, pre-service physics teachers should not only focus on one of the activities in the learning process, but also on understanding problems such as water issues from the comprehensive steps of

EDP, which incorporate science, technology, engineering, and mathematics. In addition, sufficient time is required for the worksheets to be utilized in class.

The comments of the validators and the responses of pre-service physics instructors serve as important evaluative factors. Based on the responses of pre-service physics teachers, the font size must be adjusted, and the worksheets must also indicate that they are intended for collaboration.

CONCLUSION

It can be concluded that the worksheets developed using the Engineering Design Process (EDP) model to promote Sustainable Development Goals (SDGs) were suitable for use in the pre-service physics teacher's learning process. The developed worksheet for this research is limited to only two water issues: turbidity and filtration. For further study, it is suggested that other physics learning topics be developed and that trials be conducted in multiple physics education programs.

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