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Original Research Article

Improving students' scientific literacy : Development of guided inquiry-based student worksheets on buffer solution material

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ABSTRACT

Everyone must have scientific literacy to actively participate in advancing science, technology, and society. However, the scientific literacy skills of Indonesian students are still low. This research aims to develop student worksheets based on guided inquiry on buffer solution material to increase students' scientific literacy. This research applied 4D development research which includes the Definition, Design, Development, and Dissemination stages. At the definition stage, a needs analysis was carried out, while at the design stage, a draft of the student worksheet was made. At the development stage, the worksheet was validated by 5 validators. Furthermore, the revised worksheet was tested for readability by 10 students in class XI IPA. Finally, the revised worksheet was field tested on 32 students through a learning buffer solution in class with a guided inquiry strategy. This study employed a descriptive approach to assess the validity, practicality, and effectiveness of the worksheet. The findings indicate that the developed worksheet is highly valid, with an average validity score of 94.11% across the content, presentation, media, and language aspects, placing it in the very valid category. The worksheet also achieved a practicality score of 84%, indicating it is practical. Additionally, the worksheet improved students' scientific literacy with an N-gain value of 0.59. Therefore, it can be concluded that the worksheet can be used to improve students' scientific literacy through buffer solution learning.

Introduction

Education is one sector that greatly influences the development of a nation because education will produce successful and high-quality human resources who will manage a nation. Education is the main basis for contributing to all sectors by providing the necessary skills and knowledge (Anil, 2019). However, until now there are still many problems in education which are a challenge for the Indonesian government and can be proven by the low level of scientific literacy among students in Indonesia. Scientific literacy is a person's ability to apply their knowledge to identify questions, construct new knowledge, provide scientific explanations, draw conclusions based on scientific evidence, and the ability to develop a reflective mindset so that they can participate in addressing issues and ideas related to science (OECD, 2019). Scientific literacy is one of the scientific disciplines in the International Program for Student Assessment (PISA) that focuses on students' ability to use scientific knowledge and skills (Khairi & Ikhsan, 2022).

In a survey conducted by PISA released by the OECD in 2019, Indonesia was ranked 62nd out of 70 countries regarding the level of scientific literacy (Utami, 2021). Rusmansyah et al. (2021) found that students' scientific literacy was still low or 23% of achievement. The low of students' scientific literacy abilities in Indonesia are generally caused by learning activities that are not yet oriented toward developing scientific literacy. revealed that low scientific literacy is caused by several factors such as school infrastructure, school human resources, and school management (Ardianto & Rubbini, 2016). The low scientific literacy abilities also influenced by the curriculum and education system, the choice of teaching methods and models by teachers, learning tools and facilities, as well as teaching materials (Sutrisna, 2021).

The learning strategies and assignments provided by teachers fail to sufficiently challenge students to explore information in depth and breadth. Moreover, the potential of interactive and engaging learning media has not been fully utilized. Chemistry instruction in classrooms tends to focus predominantly on theory and mathematical concepts, often neglecting other approaches. As a result, students struggle with understanding buffer solution material (Sariati et al., 2020). This leads to a relatively low level of conceptual understanding, which is a crucial component of scientific literacy, particularly regarding buffer solutions.

Nahdiah et al. (2017) stated that the low scientific literacy of students in Indonesia can be overcome by improving the learning process by using learning media that are interactive, and creative and build creativity. Through interactive media learning it will be depicted in the form of computer technology with various animated images that are more interesting so that students can learn chemistry easily. One of the determining factors for success in the learning process is using learning resources (Pratama & Saregar, 2019). Learning resources are tools that can be used as intermediaries to increase effectiveness and efficiency in achieving goals (Jafnihirda et al., 2019). Learning resources can help students concretize concepts and motivate students to learn actively. Student worksheets are a learning resource that can be used as a solution so that learning focuses on students.

Student worksheet is a student guide that is used to carry out problem-solving activities. Student worksheet makes it very easy for teachers to carry out learning, as well as for students. Student worksheet can help students learn both directly at school and independently (Petri & Suryelita, 2022). The structure of student worksheet generally consists of several components including title, learning instruction, competencies to be achieved, supporting information, and worksheets. Student worksheet can also change the paradigm teacher-centered becomes student-centered so that students will be more active. According to Pratiwiet al. (2018) the aim of using student worksheets is to find out understanding of concepts, train students' skills, as practical instructions, as a learning guide, and can help students apply and integrate various concepts that have been discovered.

Worksheets function as a tool to support learning by providing structured activities that guide students to achieve the expected learning objectives. If the learning objective is to improve scientific literacy, then the worksheet can be structured based on problem-solving-orientated learning stages such as guided inquiry, problem-based learning, or project-based learning (Erdani et al., 2020; Andriani & Masykuri, 2021; Sholahuddin et al., 2023). In the case of worksheet integration with guided inquiry learning, the worksheet helps in organizing thoughts, formulating hypotheses, exploring data, analyzing data, and making conclusions (Agustin & Sukarmin, 2024). For example, worksheets may include questions that encourage students to think critically about the relationships between different scientific concepts.

Guided inquiry encourages students to be more active, creative, and critical, allowing them to develop their ideas freely and in-depth, and to express their imagination and thoughts. It also guides students in discovering concepts through various sources of information, leading to new understanding. The guided inquiry model offers several advantages, including helping students to (1) better grasp fundamental concepts and ideas, (2) utilize memory and cognitive abilities to make connections with the lessons learned, (3) take initiative and formulate their own hypotheses, and (4) experience deep satisfaction from their discoveries. Additionally, guided inquiry makes the learning process more meaningful (Handayani & Suparman, 2020).

Several studies on the development of worksheets have been conducted, both those not integrated with problem-solving-based learning models or strategies and those that are integrated. Both types have been shown to improve students' learning outcomes including scientific literacy. Integrated worksheets with learning strategies or models have the advantage of making the learning stages more systematic, based on the underlying strategy or model's syntax. Meanwhile, non-integrated worksheets also offer the benefit of flexibility in their use across various learning strategies or models.

Ulya & Rusmini (2022) found that developing a worksheet without integrating the guided inquiry model produced a worksheet rated as very valid, very practical, and moderately effective in enhancing students' scientific literacy skills in the topic of reaction rates. Izzatunnisa et al. (2019) created a discovery-based worksheet that was also deemed very valid, practical, and moderately effective in improving students' scientific literacy in the chemistry of electrolyte and non-electrolyte solutions. Additionally, other researchers have integrated problem-solving-based learning strategies or models, such as problem-based learning for the colloid topic (Lestari et al., 2022; Tofanao et al., 2022) and for the acid-base solution topic (Danial et al., 2022), resulting in worksheets that effectively meet knowledge-based learning objectives. Riyani et al. (2017) developed worksheets following stages of preliminary development, planning, preparation, and evaluation, which resulted in worksheets deemed valid by expert assessment. However, these worksheets were not effective in improving learning outcomes. The limitation of this research lies in the lack of a micro-cycle process in the development method, leading to the absence of ongoing revisions.

In contrast to previous studies, this research focuses on developing student worksheets that incorporate the benefits of guided inquiry, particularly the use of scientific process skills to build knowledge, solve problems, and make decisions through systematic scientific stages in the context of buffer solution material. The subject of buffer solutions is closely tied to real-world issues, such as their use in medications, food, and blood. By linking everyday experiences with the concepts being taught, the learning process becomes more meaningful for students. So, the development of these guided inquiry-based worksheets on buffer solutions is expected to enhance students' scientific literacy. The development process should incorporate micro-cycles, like those in the ADDIE model, to create a product that is valid, practical, and effective. Additionally, the findings of this research aim to support student learning and offer valuable insights for both teachers and students, helping to optimize the use of learning resources in the educational process.

Methods

This research utilized the 4D development model proposed by Thiagarajan et al. (1974), which includes four stages: define, design, develop, and disseminate, as illustrated in Fig-1. This research involved five validators, including four chemistry education experts and a chemistry teacher, to assess the developed buffer solution worksheet and other research instruments. The study also included 10 students from class XI IPA 2 of MAN 3 Banjarmasin for a readability test of the worksheet and 30 students for a field test conducted in a real classroom setting. The research focused on a guided inquiry-based worksheet and related learning tools. The instruments used in the study included validation sheets, questionnaires for teacher and student feedback, observation sheets, and scientific literacy test instruments. The procedure for testing the worksheet's effectiveness was designed using a one-group pre-experimental design with pre-test and post-test, as shown in Table 1.

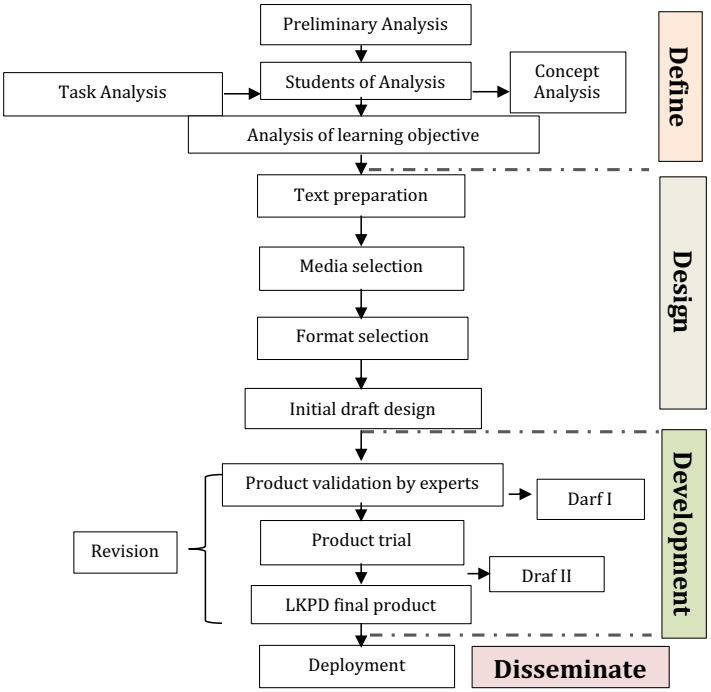

Fig-1. 4D development model

The data analysis conducted included evaluating the content validity of the worksheet by five validators. The indicators for content validity included content, presentation, language, and media. The data was calculated as a percentage and interpreted into a validity score, with a minimum result of 70% indicating that the worksheet is valid and suitable for use (Akbar, 2015). The percentage of 85.01– 100.00 = very valid, 70.01– 85.00% = valid, 50.01 – 70.00% = poor, and ≤50.00% = very poor.

Tabel 1. One-group pre-test and post-test experimental design

O1 Pre-test	X Treatment	O2 Post-test
Literacy test science with 10 essay questions	Learning using LKPD guided inquiry-based	Literacy test science with 10 essay questions
O1	X	O2
Pre-test	Treatment	Post-test
Literacy test science with 10 essay questions	Learning using LKPD guided inquiry-based	Literacy test science with 10 essay questions

The practicality of the worksheet was assessed through a readability questionnaire, teacher and student response questionnaires, an observation sheet on the teacher's ability to use the worksheet, and an observation sheet on the implementation of learning. The assessment criteria were based on a Likert scale with five scales. Then the Likert score is converted into a percentage score. A percentage score of 81-100 = very practical, 61-80 = practical, 41-60 = moderate, 21-40 = low, and ≤ 20 = very low (Widoyoko, 2018).

The effectiveness of the worksheet is evaluated based on the N-gain value for scientific literacy. An N-gain value of $g > 0.7$ is considered high, $0.3 \leq g < 0.7$ is moderate, and $g < 0.3$ is low in terms of scientific literacy skills. An N-gain score of ≥ 0.3 indicates that the worksheet is effective and appropriate for use (Hake, 1998).

Results and Discussion

This research was conducted using the 4D development model, which includes the definition, design, development, and dissemination phases. The outcome of this research is a guided inquiry-based worksheet on buffer solution material for class XI science students, designed to enhance students' scientific literacy.

Define Stage

In the initial stages of designing a guided inquiry-based worksheet, several qualitative content analyses were carried including student analysis, concept task analysis, and learning objective analysis. Student analysis indicated that students have been introduced by the teacher to the guided inquiry model which has received a positive response. In learning activities, teachers have used learning resources such as textbooks and power points, although in reality there are still some students who do not focus on learning and have difficulty understanding chemistry learning concepts. Therefore, in presenting chemistry material to make it more interesting, teachers must be able to choose the right learning resources to use, so that the expected competency standard learning objectives can be achieved by students. For this reason, a guided inquiry-based worksheet learning resource was developed which is expected to be able to overcome these problems.

Students need to have prior knowledge of acid-base solutions and their reactions. Additionally, they should understand the concept of buffer solutions and be able to apply this knowledge to calculate the pH of buffer solutions and their real-life applications. According to concept and task analysis, the learning objectives for buffer solution material are: (1) Students should be able to explain the principles of buffer solutions, perform pH calculations, understand their role in living organisms, and prepare buffer solutions with specific pH values.

Design Stage

The guided inquiry-based worksheet was designed based on student feedback, which showed that students appreciated and responded positively to the worksheet to improve their understanding. It integrates text, animated images, and chemical reactions into a unified approach to chemistry learning, aiding in the comprehension of chemical topics. The final version of the worksheet is saved in PDF format, as shown in Fig-2.

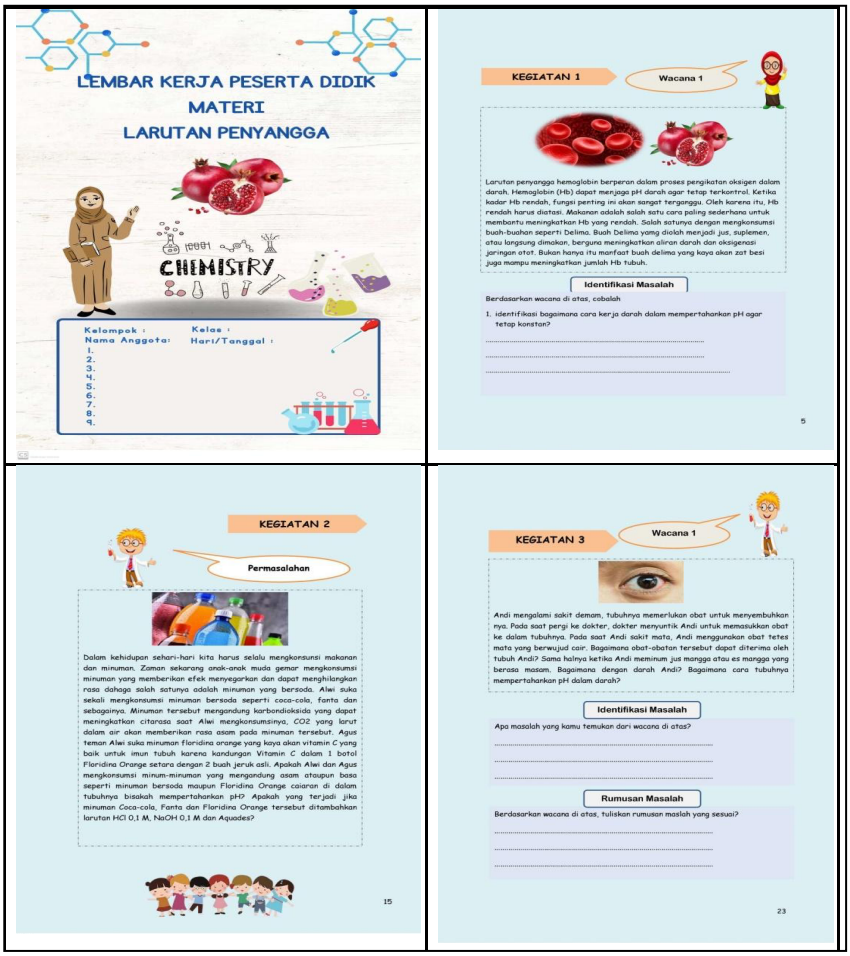

Fig-2. Display of the worksheet

Following the final revision based on the validator's suggestions, the development of the worksheet learning resource was completed. Fig-2 shows parts of activities 1, 2, and 3, and the worksheet is considered suitable for use in this research.

Develop Stage

In this development stage, a small-group trial and a field test in a real classroom setting were conducted. This phase of development assessed the validity, practicality, and effectiveness of the developed worksheet. The results of these trials are presented in the following discussion.

Validity

According to the validity analysis in Fig-3, the media aspect received the lowest percentage at 90.85%, while the other aspects exceeded this percentage. The overall percentage for the worksheet was 94.11%, as shown in the figure above. According to Akbar (2015), a validity value of 94.11% falls into the "very valid" category, making it suitable for use as a learning resource in the teaching and learning process.

Practicality

Table 2 shows the overall results of filling out the questionnaire with a percentage result of 84%. Based on this percentage, according to Widoyoko (2018), the percentage shows that the worksheet developed is very practical and suitable for use as a chemistry learning resource in schools.

Effectiveness

The effectiveness of the worksheet was determined based on the results of the analysis of student scientific literacy test data after participating in the limited field trial stage. The scientific literacy data from the pre-test and post-test were evaluated using N-Gain values. The analysis results, based on the students' average achievement, are presented in Table 2. Table 3 shows that students' science literacy increased from 24.06 (low category) to 70.10 (high category) after using the guided inquiry-based worksheet. The increase in science literacy scores based on science literacy competencies shows the effectiveness of the worksheet developed in this study. The improvement of students' scientific literacy skills based on the N-gain score is presented in Fig-4.

Table 2. Worksheet practicality calculation

Practicality Component	Mark (%)	Information
Legibility	78	Practical
Student Response Questionnaire	78	Practical
Teacher Response Questionnaire	90	Very Practical
Observation Sheet on Teacher's Ability to Use worksheet	87	Very Practical
Learning Implementation Observation Sheet	85	Very Practical
Rate-Rata	84	Very Practical

Table 3. Scientific literacy scores

Test	Min	Max	Mean
Pre-test	0	43.33	24.06
Post-test	0	86.67	70.10

Figure 4 showed that increasing scientific literacy competency occurred in each aspect after students participated in learning using guided inquiry-based worksheets. The worksheet used by students in learning is designed based on the stages of the guided inquiry learning model systematically. The main stages of learning include stating the problems, formulating hypotheses, designing experiments, exploring data, analyzing data, and making conclusions (Agustin & Sukarmin, 2024). Worksheets include questions that encourage students to think critically about the relationships between different scientific concepts. Thus, students' knowledge of buffer solutions is more in-depth. In-depth knowledge greatly supports students' ability to solve related problems better.

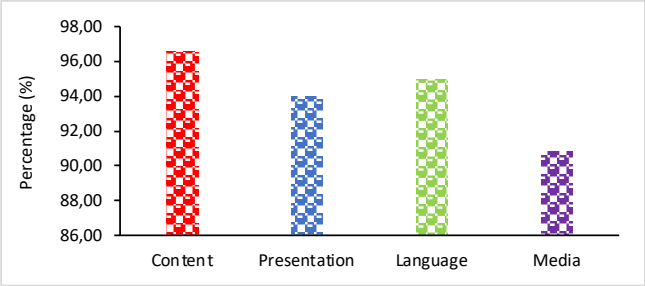

Fig-3. Worksheet validation results

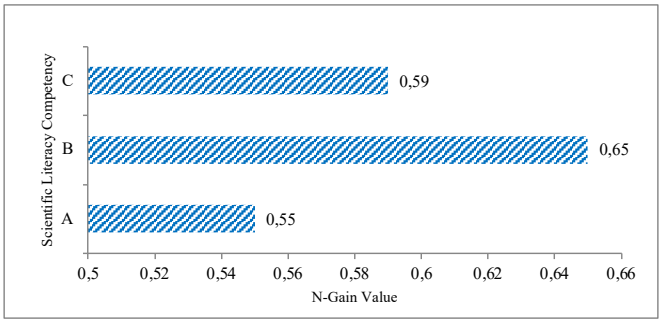

Fig-4. N-gain value of scientific literacy test. A (Explaining scientific phenomena); B (Evaluating and designing scientific research); C (Interpreting scientific data and evidence)

Sholahuddin & Shadriyah (2017) found that high school students achieved better learning outcomes and process skills when they learned using a guided inquiry strategy than direct instruction or free inquiry. In the guided inquiry strategy, students are not fully released because their learning autonomy is still not developed enough. Teachers still provide assistance or scaffolding needed by students, especially through the worksheets so that students learn more systematically and easily. For example, in all stages of guided inquiry, one form of scaffolding is that the experimental design has been determined by the teacher in the worksheet because it requires abilities that are too complex for students. Meanwhile, other stages are carried out by students themselves based on the worksheet provided.

The results of this study reinforce previous findings that the application of guided inquiry learning strategies helps students develop diverse competencies and knowledge. The guided inquiry strategy is very appropriate for science learning, especially for students at the high school level who still need scaffolding from educators (Riyani, et al., 2017; Sholahuddin and Shadriyah, 2017). The guided inquiry learning model is also able to provide positive and significant gains in student learning outcomes (Pratiwi et al., 2019).

This research revealed that all scientific literacy competencies fall within the medium category, indicating that the developed worksheet effectively enhances these competencies. This finding is consistent with research by Sholahuddin et al. (2020), which demonstrated that guided inquiry learning strategies, whether utilizing environmental or other learning resources, are effective in improving students' scientific literacy. Such strategies promote optimal student engagement in learning activities through the steps of the scientific method, thereby facilitating meaningful learning experiences. Aulia (2019) also found that guided inquiry-based learning is effective in enhancing scientific literacy skills across various aspects, including context, competence, knowledge, and all indicators of attitude, which improved to a good level. As a result, guided inquiry not only supports better knowledge retention but also develops process skills, which are essential for scientific literacy. Strong scientific literacy enables students to not only grasp concepts but also apply their knowledge to scientifically explain phenomena and solve real-world problems.

Dissemination Stage

At this final stage, the developed worksheet is distributed to teachers and students for use in teaching buffer solutions in chemistry classes. Additionally, the research findings are published in a scientific journal to reach a broader educational audience.

Up to the final stage of this research, a prototype of a worksheet could be used on a limited scale of learning. This prototype has the potential for further enhancement through extensive trials to create a high-quality product that consistently achieves learning outcomes. The worksheet could also be tested in outdoor learning settings to boost students' scientific literacy (Fan et al., 2024). Outdoor education provides a dynamic and engaging learning environment that fosters creativity within the scientific literacy skillset. By engaging students in real-world experiences and offering opportunities for exploration and experimentation, outdoor education ignites curiosity, critical thinking, and problem-solving skills, all of which are vital to scientific literacy (McAnally et al., 2018; Pambudi, 2022).

Conclusion

Based on the research data, the following findings were identified: (1) This research resulted in a guided inquiry-based worksheet, developed using a 4D model, available in a printed version and saved in PDF format. (2) The guided inquiry-based worksheet was found to be suitable in terms of validity, practicality, and effectiveness. The worksheet is considered highly valid, with an average validity score of 94.11% across content, presentation, media, and language aspects. It is also deemed very practical, with a score of 84%, and effective as a learning resource, with an N-gain value of 0.59 in the medium category. After implementing the guided inquiry-based worksheet in the classroom, it was found to be effective in improving students' scientific literacy on buffer solution material. While the product can be used on a limited scale to enhance students' scientific literacy in chemistry, broader trials are needed to ensure consistent results and further refine the worksheet for widespread application. Future research could also investigate the connections between knowledge, process skills, and scientific literacy in experimental settings using the developed worksheet.

Conflict of Interests

The author declares that there is no conflict of interest between this research and the manuscript.

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