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Design of an Electronic Worksheet Using a Problem-Based Learning Approach Oriented to ESD: Application of Buffer Concepts in the Cheese Industry to Train Students' Scientific Literacy

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Abstract: Design of an Electronic Worksheet Using a Problem-Based Learning Approach Oriented to ESD: Application of Buffer Concepts in the Cheese Industry to Train Students' Scientific Literacy. Students' science literacy in Indonesia remains relatively low and needs to be improved through contextual and meaningful learning. One approach that can be taken is to integrate Problem-Based Learning (PBL) and Education for Sustainable Development (ESD) into interactive teaching materials. This study aims to develop PBL-based e-worksheets integrated with ESD on the topic of buffer systems within the context of the cheese industry to enhance students' science literacy. The method used is Design and Development Research (DDR), which includes the planning, production, and evaluation stages. The planning stage was conducted through a need analysis involving high school chemistry teachers, while the production stage involved the design and development of the e-worksheet, which was then validated by two lecturers and two chemistry teachers. The evaluation stage was conducted through a pilot test with 30 11th-grade high school students. The research results indicate that the developed e-worksheet possesses excellent quality, with a 100% feasibility rate across all evaluation aspects. Pilot test results show that students' science literacy falls within the good to excellent categories, particularly regarding the ability to organize information, analyze data, and connect concepts to sustainability issues such as the SDGs and the circular economy. However, their ability to formulate problems and engage in deep scientific reasoning still needs improvement. Thus, this e-worksheet is deemed suitable for use and can foster science literacy through contextual, interactive, and sustainability-oriented learning.

Keywords: Scientific literacy, Problem-Based Learning (PBL), Education for Sustainable Development (ESD), Electronic worksheet / E-worksheet, Buffer system concept

Abstrak: Perancangan Lembar Kerja Elektronik Berbasis Problem-Based Learning Berorientasi ESD: Penerapan Konsep Larutan Penyangga pada Industri Keju untuk Melatih Literasi Sains Peserta Didik. *Literasi sains peserta didik di Indonesia masih tergolong rendah dan perlu ditingkatkan melalui pembelajaran yang kontekstual dan bermakna. Salah satu upaya yang dapat dilakukan adalah dengan mengintegrasikan pendekatan Problem-Based Learning (PBL) dan Education for Sustainable Development (ESD) dalam bahan ajar interaktif. Penelitian ini bertujuan untuk mengembangkan lembar kerja elektronik (e-worksheet) berbasis PBL terintegrasi ESD pada materi sistem penyangga dalam konteks industri keju untuk melatih literasi sains peserta didik. Metode yang digunakan adalah Design and Development Research (DDR)*

yang meliputi tahap perencanaan, produksi, dan evaluasi. Tahap perencanaan dilakukan melalui analisis kebutuhan dengan melibatkan guru kimia SMA, sedangkan tahap produksi meliputi perancangan dan pengembangan e-worksheet yang kemudian divalidasi oleh dua dosen dan dua guru kimia. Tahap evaluasi dilakukan melalui uji coba terbatas kepada 30 siswa kelas XI SMA. Hasil penelitian menunjukkan bahwa e-worksheet yang dikembangkan memiliki kualitas sangat baik dengan persentase kelayakan 100% pada seluruh aspek penilaian. Hasil uji coba menunjukkan bahwa literasi sains peserta didik berada pada kategori baik hingga sangat baik, terutama dalam kemampuan mengorganisasi informasi, menganalisis data, dan mengaitkan konsep dengan isu keberlanjutan seperti SDGs dan ekonomi sirkular. Namun, kemampuan dalam merumuskan masalah dan penalaran ilmiah yang mendalam masih perlu ditingkatkan. Dengan demikian, e-worksheet ini dinyatakan layak digunakan dan dapat melatihkan literasi sains melalui pembelajaran yang kontekstual, interaktif, dan berorientasi keberlanjutan.

Kata kunci: *Literasi sains, Problem-Based Learning (PBL), Pendidikan untuk Pembangunan Berkelanjutan, Lembar kerja elektronik, Konsep sistem penyangga*

▪ INTRODUCTION

Twenty-first century education requires students to possess competencies that are not only cognitive in nature but also include values, mindsets, and the ability to adapt to rapid changes. Among these competencies, the 4C skills (communication, collaboration, critical thinking, and creative thinking) play a crucial role in preparing students to face global challenges (Wang et al., 2018; Yuliana & Irawan, 2024). In addition, scientific literacy is considered an essential skill that enables individuals to understand scientific concepts, apply them in daily life, and make evidence-based decisions (OECD, 2023). Scientific literacy refers to an individual's ability to understand and apply scientific concepts in everyday life. It also encompasses understanding the characteristics of science, awareness of how science and technology shape natural, intellectual, and cultural environments, as well as a willingness to engage with and care about science-related issues (OECD, 2023).

However, students' scientific literacy in Indonesia remains relatively low. The Programme for International Student Assessment (PISA) 2022 results indicate that Indonesia ranked 67th out of 79 countries with a score of 383, below the global average of 485 (OECD, 2023). This condition is attributed to students' limited ability to relate scientific concepts to real-life contexts, as well as their low critical thinking and problem-solving skills (Sopandi, 2019). Therefore, innovative learning approaches are needed to foster scientific literacy through meaningful and contextual learning experiences.

One relevant approach is Education for Sustainable Development (ESD), which emphasizes the integration of environmental, social, and economic dimensions in learning. ESD aims to equip learners with the knowledge and skills necessary to address global challenges and to make responsible decisions for sustainable futures (UNESCO, 2020). In Indonesia, the implementation of ESD aligns with the Merdeka Curriculum, which promotes meaningful, flexible, and contextual learning while strengthening students' literacy and 21st-century skills (Kemendikbudristek, 2024).

To support this approach, innovative and interactive teaching materials are required, one of which is the electronic worksheet (e-worksheet). The use of e-worksheets enables more flexible, structured, and contextual learning. To effectively train scientific literacy, e-worksheets should be designed using appropriate instructional models such as Problem-Based Learning (PBL). PBL engages students in solving real-world problems, encouraging them to think critically, collaborate, and construct knowledge through inquiry (Pertiwi et al., 2023; Sartika, 2018), and has also been shown to enhance students'

motivation and learning outcomes, with a meaningful relationship between learning motivation and achievement (Eglesyes & Estria, 2025).

In chemistry learning, buffer solution concepts are closely related to real-life applications, particularly in the food industry. For instance, in cheese production, maintaining pH stability is essential to ensure optimal fermentation processes and product quality. Buffer solutions play a significant role in maintaining pH balance, making this topic highly relevant to be integrated into ESD-oriented learning contexts (Oktavia, 2025).

Previous studies have shown that the use of worksheets can enhance student engagement and learning motivation (Inayati, 2021). However, existing worksheets are generally limited to printed formats and have not integrated PBL, ESD principles, or been specifically designed to train scientific literacy. This gap highlights the need for developing more innovative instructional materials.

Therefore, this study aims to develop an ESD-oriented electronic worksheet based on Problem-Based Learning on the topic of buffer applications in cheese production. The developed product is expected to be valid and feasible, as well as capable of training students' scientific literacy through meaningful and contextual learning activities.

▪ METHOD

This study employed Design and Development Research (DDR) aimed at developing an instructional product (Richey & Klein, 2007). DDR is a systematic study of design, development, and evaluation processes to produce instructional products and their development models. This method consists of three main stages, namely planning, production, and evaluation.

The planning stage was conducted to analyze learning needs through a preliminary study in Grade XI senior high school. Data were collected through a survey distributed to chemistry teachers using Google Forms to identify problems in chemistry learning. Furthermore, an analysis was conducted on the Merdeka Curriculum learning outcomes, the Pancasila Student Profile, and scientific literacy, focusing on knowledge, skills, and attitudes. In addition, the integration of ESD and the PBL model was analyzed as the foundation for product development.

The production stage involved the design and development of an electronic worksheet (e-worksheet) based on PBL and ESD. This stage included initial design development, digital product creation, and revision based on expert feedback. Product validation was carried out by two chemistry lecturers and two chemistry teachers to assess content validity, construct validity, and presentation quality, which served as the basis for product revision.

The evaluation stage was conducted through a limited trial involving 30 Grade XI students from SMA Negeri 1 Margahayu, Bandung. The trial aimed to examine the implementation of the e-worksheet and to analyze students' scientific literacy profiles based on their responses. The sample was randomly selected from a single class without grouping based on academic ability. In addition, validators also assessed the product using validation sheets provided.

Data analysis techniques in this study were carried out by processing, analyzing, and interpreting the collected data to address the research objectives. Data from the validation of the Electronic Student Worksheet, which includes content, construct, and technical aspects, were analyzed descriptively using the Guttman scale with "Yes" (score 1) and "No" (score 0) responses (Ridwan, 2018). The obtained scores were then summed, converted into percentages, and interpreted based on validation criteria to determine the feasibility of the product. Meanwhile, data on students' scientific literacy profiles were obtained through the assessment of their responses to the Electronic Student Worksheet using a scoring rubric. The scores from both instruments were processed in the same manner and then categorized to determine the level of students' scientific literacy based on predetermined criteria.

▪ RESULT AND DISCUSSION

A. Results of the Needs Analysis of the Electronic Worksheet

The needs analysis was conducted involving 13 chemistry teachers from senior high schools in Bandung City and Bandung Regency. Based on the responses obtained, information was gathered regarding classroom conditions related to the use of worksheets, the implementation of Problem-Based Learning (PBL), the development of scientific literacy, the application of Education for Sustainable Development (ESD) principles, and the relevance of industrial contexts in buffer solution topics. The findings of this survey serve as a foundation for designing learning materials that are more targeted, contextual, and capable of enhancing students' scientific literacy.

The results indicate that all teachers support the development of an ESD-integrated electronic worksheet based on PBL and oriented toward scientific literacy in chemistry learning. The teachers also agreed that learning should be connected to real-world phenomena, including the application of buffer solutions in cheese production within the food industry, as it can improve conceptual understanding, critical thinking skills, and the relevance of learning for students. Despite challenges such as the complexity of worksheet development, all respondents considered that the development of an ESD-oriented PBL electronic worksheet is highly necessary to improve students' scientific literacy skills.

These findings are consistent with the view that scientific literacy refers to an individual's ability to identify scientific issues, evaluate information based on sources and methods, and draw evidence-based conclusions (Haruna et al., 2023). Scientific literacy also has strategic value as it contributes to societal development, scientific advancement, and the improvement of quality of life (Laugksch, 2000). Therefore, the development of learning materials that support scientific literacy is essential in the educational context.

The integration of ESD principles into learning is also highly relevant, as ESD is considered a promising innovation for implementation in Indonesia and can be integrated across all educational levels and subject areas (Hariyono et al., 2018; Indrati & Hariadi, 2016; Jegstad & Sinnes, 2015; Rahman et al., 2019; Rahmawati et al., 2021; Sund & Gericke, 2020). By linking chemistry concepts to real-world contexts such as the food industry, learning becomes more meaningful and contextual.

Furthermore, curriculum demands that emphasize active and contextual learning (Syafitri & Tressyalina, 2020) reinforce the need for appropriate learning media, such as worksheets. Worksheets function as tools to facilitate effective interaction between teachers and students and to improve learning outcomes, as they can be designed according to learning needs and conditions (Syafitri & Tressyalina, 2020; Irwansyah & Perkasa, 2022). In this regard, the use of instructional models such as PBL is essential, as it provides a systematic framework for organizing learning experiences to achieve instructional objectives effectively (Darmadi, 2017).

Therefore, the development of an ESD-integrated electronic worksheet based on PBL and oriented toward scientific literacy is not only supported by empirical needs in the field but also strengthened by relevant theoretical foundations. This indicates that the developed product has strong potential to

enhance the quality of chemistry learning in a more contextual, meaningful, and 21st-century skills-oriented manner.

B. Electronic Worksheet Development Design

1. Learning Outcomes Analysis

The electronic worksheet was developed based on the learning outcomes of the Merdeka Curriculum by integrating ESD dimensions and scientific literacy. The learning outcomes include conceptual understanding of chemistry and science process skills, with a focus on chemical equilibrium, particularly the application of buffer solutions in cheese production.

This topic is connected to issues of food security and sustainability, where proper pH control plays an important role in improving product quality, reducing waste, and supporting more efficient and environmentally friendly production processes. In addition, the learning objectives are aligned with science process skills integrated within the PBL syntax, which includes problem orientation, organizing learning, investigation, developing and presenting results, and analyzing and evaluating problem-solving processes.

The formulation of learning objectives is not only based on the Merdeka Curriculum outcomes but also integrates ESD dimensions, including environmental, social, and economic aspects, as well as scientific literacy aspects in terms of knowledge and competencies. This integration is expected to support both conceptual understanding and the development of students' skills in applying buffer concepts in the food industry, particularly in cheese production.

2. Formulation of Learning Objectives

Learning objectives serve as the basis for developing the designed worksheet. This is in line with Suryaningsih & Nurlita (2021), who state that worksheet development should be aligned with the intended learning needs and objectives. In this study, the formulation of learning objectives was carried out based on an analysis of chemistry learning outcomes in the Merdeka Curriculum related to the application of buffer concepts in cheese production within the food industry, while also considering the dimensions of ESD and scientific literacy aspects based on the PISA 2025 framework.

3. Development of the Electronic Worksheet

The electronic worksheet developed was designed based on learning objectives aligned with the Merdeka Curriculum learning outcomes, the ESD dimensions, and scientific literacy aspects. This design aims to ensure that the learning process is well-structured and supports the achievement of the expected competencies. In general, the worksheet is developed using the PBL model, which consists of five learning stages.

At the problem orientation stage, students are directed toward a contextual issue related to pH control in cheese production within the food industry to build initial understanding, motivation, and the ability to formulate scientific questions. The organizing learning stage emphasizes the collection and classification of information regarding the concept, types, and functions of buffers through group discussions. Next, in the guiding inquiry stage, students analyze the cheese-

making process, determine the optimal pH, and identify the role of buffers under the teacher's guidance as a facilitator.

At the developing and presenting results stage, students analyze the role of buffer systems in cheese production and connect it to the Sustainable Development Goals (SDGs) and the circular economy, then present their findings. The final stage, analyzing and evaluating the problem-solving process, focuses on reflection and conclusion drawing regarding the role of buffers in maintaining product quality, as well as evaluating the thinking process during learning to achieve a more meaningful and contextual understanding.

4. Development of the Electronic Worksheet Using Liveworksheets

The worksheet that had been developed was then transformed into an electronic worksheet using the Liveworksheets platform, which can be accessed online via Google. This platform was selected due to its ease of access for researchers, teachers, and students, as well as its various features that make learning more engaging, interactive, and potentially increase students' learning interest. This is supported by previous studies highlighting that Liveworksheets-based e-worksheets are feasible and practical for supporting student-centered learning environments (Sebayan & Elfrida, 2025).

In its development, two main features were utilized, namely video and open answer. The video feature was used in the developing and presenting results stage by embedding YouTube links as learning resources related to the SDGs and circular economy, allowing students to access the videos directly without scanning QR codes. Meanwhile, the open answer feature was used to provide students with space to answer essay-type questions by typing their responses directly into the provided fields. This design makes the electronic worksheet more interactive and encourages active student participation in the learning process.

5. Validation Results of the Electronic Worksheet by Lecturers and Teachers

The developed electronic worksheet was further validated to determine its feasibility based on several aspects, namely content, language clarity and readability, layout and design, alignment of instructions with the PBL model and learning objectives, as well as the assessment rubric for students' answers. The validation was carried out by four validators, consisting of two chemistry education lecturers and two high school chemistry teachers.

The validation results showed that the alignment of instructions with the PBL syntax obtained a score of 100%, categorized as very good. This indicates that all PBL stages have been well integrated into the worksheet, thereby supporting a systematic learning process. The same result was also obtained for the alignment of instructions with the learning objectives, indicating that each activity effectively supports the achievement of students' knowledge and skills competencies.

In terms of language clarity and grammar, the worksheet obtained a score of 100% with a very good category, indicating that the language used is clear, formal, and easy to understand. Meanwhile, the layout and design aspect also achieved 100%, categorized as very good, showing that the worksheet is attractive, well-structured, and facilitates students' understanding, although several suggestions for improvement were provided.

In addition, the validation of the students' answer assessment rubric was conducted to ensure its alignment with the learning objectives and its ability to objectively measure students' achievement in cognitive, psychomotor, and affective aspects. The results showed a score of 100% with a very good category, indicating that the rubric is appropriate and feasible to be used in the learning assessment process.

C. Field Trial of the Electronic Worksheet

The evaluation of the electronic worksheet pilot test was also conducted by analyzing students' responses to the tasks included in the worksheet. These responses were then assessed using validated scoring guidelines designed to evaluate responses in electronic worksheets.

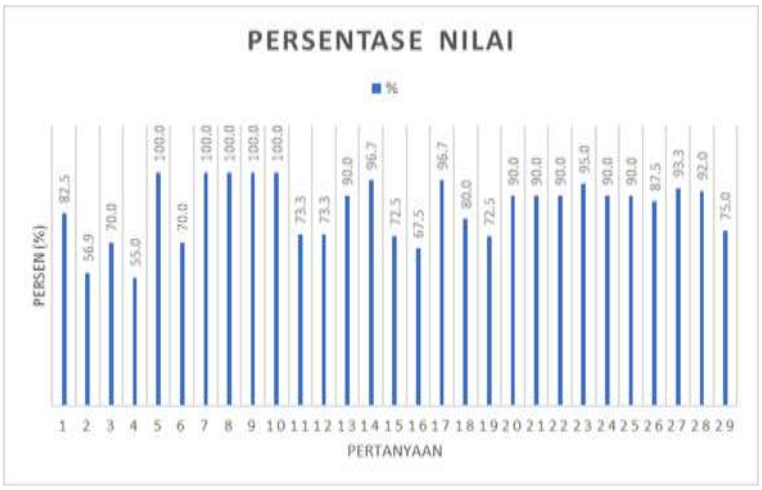

Figure 1. The percentage scores of students' responses to the tasks in the developed electronic worksheet.

a. Problem Orientation

At the problem orientation stage, which corresponds to the first stage of PBL where students identify what they need to know to solve a problem (Escribano & del Valle, 2008), students' scientific literacy can be observed through their ability to interpret information and relate it to scientific phenomena related to pH in cheese production. Question number 1 obtained a percentage of 82.5% (very good), question number 2 was 57% (sufficient), question number 3 was 70% (good), and question number 4 was 55% (low). These results indicate that students are generally able to understand information from the text and relate it to scientific concepts; however, the depth of explanation and problem formulation skills are still uneven.

Some students still provided general and less structured answers, particularly in linking pH concepts to cheese quality in a scientific manner. This reflects that, although students have begun to identify relevant knowledge, they still experience difficulties in formulating problems, which are essential in the initial stage of PBL. Scientific literacy emphasizes the ability to explain scientific phenomena and interpret evidence-based information (OECD, 2023). Therefore, students' scientific literacy at this stage is developing but not yet optimal, especially in analysis and synthesis skills.

b. Organizing Learning

This stage aligns with the second stage of PBL, where students independently search for information to support problem-solving (Escribano & del Valle, 2008). At this stage, students demonstrated very strong understanding of buffer concepts. Questions number 5, 7, 8, and 9 reached 100% (very high), while question number 6 obtained 70% (good). These results indicate that students are able to understand and organize scientific information well, particularly in classifying buffer types and explaining their differences in cheese production contexts.

However, some answers were still not accompanied by complete scientific reasoning. This suggests that while students are capable of gathering and organizing relevant information, their ability to critically evaluate and justify that information remains limited. According to OECD (2023), scientific literacy includes not only understanding concepts but also providing explanations based on scientific evidence.

c. Guided Inquiry

This stage reflects the third phase of PBL, in which students collaboratively discuss information and develop strategies to solve the problem (Escribano & del Valle, 2008). Student performance ranged from good to very high, with percentages between 67.5% and 100% for questions 10-19. Students were able to understand scientific procedures, interpret data, and identify information from texts, tables, and figures provided in the worksheet.

Overall, students demonstrated the ability to explain scientific processes and use information collaboratively to answer questions. The group interaction process in PBL supports deeper understanding through discussion and clarification of concepts. However, in some items, weaknesses were still found in connecting concepts with deeper scientific reasoning, especially in explaining cause-and-effect relationships. This indicates that scientific literacy in terms of reasoning and evidence use is developing but not yet fully optimal. OECD (2023) states that scientific literacy involves the ability to use scientific evidence to explain phenomena, not merely describe results.

d. Developing and Presenting Results

This stage corresponds to the final stage of PBL, where students construct and present solutions in various forms such as reports or presentations (Escribano & del Valle, 2008). At this stage, all results were in the very good category, ranging from 90% to 95% for questions 20-25. Students were able to interpret graphs, analyze data, compare conditions, and apply buffer concepts in calculations such as the Henderson-Hasselbalch equation.

This indicates that students are capable of synthesizing information and presenting well-structured solutions based on scientific concepts. Their scientific literacy in terms of data interpretation, scientific analysis, and concept application is very strong. Students not only understand the provided information but are also able to use it to explain scientific phenomena accurately and systematically. This reflects strong scientific literacy at the level of data analysis and evidence-based reasoning (OECD, 2023).

e. SDGs and Circular Economy Analysis

At this stage, students achieved very high results, namely 87.5% for question 26, 93% for question 27, and 92% for question 28. These findings show that students are able to connect buffer concepts in the food industry with global sustainability issues such as the SDGs and the circular economy.

Students were able to explain the relationship between chemistry concepts and environmental, social, and economic aspects, including waste reduction, production efficiency, and food safety improvement. This indicates that students' scientific literacy has reached a higher level, namely the ability to integrate scientific concepts with global contexts. This aligns with the SDGs framework (United Nations, 2015) and the circular economy concept (Ellen MacArthur Foundation, 2013), which emphasize sustainability in production and consumption systems.

f. Analyzing and Evaluating Problem-Solving Processes

In line with the evaluation component in PBL, where students' solutions and individual contributions are assessed, including through reflection (Escribano & del Valle, 2008), this stage shows that students obtained a score of 75% (good). This result indicates that students are able to draw conclusions based on the learning process, but are still not optimal in integrating concepts with broader contexts such as SDGs and the circular economy.

Some students still wrote simple conclusions focusing only on buffer concepts without linking them to sustainability aspects. This suggests that students' reflective and evaluative thinking skills are still developing. According to OECD (2023), strong scientific literacy includes the ability to evaluate and connect scientific concepts with real-world issues in a comprehensive manner. Therefore, although students have achieved good results, their ability to integrate scientific understanding into broader socio-scientific contexts still needs improvement.

▪ CONCLUSION

Based on the needs analysis, design, validation, and field trial, the ESD-based electronic worksheet integrated with PBL is considered relevant and feasible for use in chemistry learning. Teachers strongly support its development because it connects chemistry concepts with real-world contexts, particularly the application of buffer solutions in cheese production, and is considered effective in improving students' conceptual understanding, critical thinking skills, and scientific literacy. The design is aligned with the Merdeka Curriculum, integrates ESD dimensions and scientific literacy, and is structured according to the five stages of PBL, making learning more meaningful and contextual.

The validation results show that the product has excellent quality across all aspects (100%), including content, language, design, alignment with PBL, and assessment rubrics. The field trial results also indicate that students' scientific literacy is generally in the good to very good category, especially in organizing learning, developing and presenting results, and analyzing SDGs and the circular economy. However, students still need improvement in problem formulation, deeper reasoning, and connecting chemistry concepts with sustainability issues such as SDGs and the

circular economy. Overall, the worksheet is feasible to use and has strong potential to enhance scientific literacy in chemistry learning.

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