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Practical Tools Review Based on Physics, Chemistry, and Biology Parameters to Train Systems Thinking Skills

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Abstract: This research aims to develop an integrated practical tool for water pollution, covering physics, chemistry, and biology parameters to enhance students' systems thinking skills. Using the 4D development model (Define, Design, Develop, Disseminate), this R&D study identifies a critical gap: 94% of teachers are unfamiliar with pH-4502C sensors, and 78% do not recognize systems thinking indicators. The developed tool integrates digital sensor technology for real-time water quality monitoring. Expert validation and teacher trials indicate the product is highly effective, with 83% of educators agreeing it facilitates the training of systems thinking at levels A, B, and C. The results show a significant improvement in students' ability to identify system components and analyze dynamic interrelationships compared to conventional methods. It is concluded that this integrated tool successfully bridges the technological gap in junior high school labs while providing a concrete framework for mastering higher-order thinking skills in environmental education.

Keywords: Practical tools; System thinking skills; Water pollution

Introduction

One of the essential skills needed by future generations to face the highly complex challenges of the 21st century is systems thinking skills (Faza et al., 2023). Systems thinking is a skill that enables each individual to understand and analyze problems, involving the ability to see the relationships between components within a system and how these interactions affect the entire system (Chaidir et al., 2024). Systems thinking skills are considered important because they facilitate students in organizing thoughts systematically and identifying correlations between seemingly unrelated problems (Susanto et al., 2025).

Systems Thinking Skills are part of higher-order thinking skills (HOTS) that are characterized by complexity and analysis (Assaraf & Orion, 2005). The characteristics of systems thinking skills are divided into eight dimensions, including: identifying system components, understanding relationships between components, recognizing dynamic relationships, organizing components within a relational framework, understanding the cyclical characteristics of systems, generalizing abilities, understanding implicit dimensions, and temporal thinking abilities. Understanding and mastering these competencies enable students to comprehend the dynamics of living systems and contribute to sustainable problem-solving (Nuraeni et al., 2020).

However, international evaluations through the Programme for International Student Assessment (PISA), coordinated by the Organization for Economic Co-operation and Development (OECD), show a decline in systems thinking skills. The 2022 data is lower than in 2018. This indicates that students' systems thinking competencies in Indonesia remain at an alarming level. This phenomenon reflects a significant gap between the urgency of developing systems skills and the reality on the ground.

The context of environmental pollution, particularly water pollution resulting from industrial activities, can be a suitable setting for applying a systems thinking

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approach (Hapsari et al., 2020a, 2020b; Sari & Kurniawan, 2021). Fruit processing industries, such as pineapples, produce liquid waste containing chemical compounds that have the potential to pollute river ecosystems through uncontrolled discharge mechanisms. The intensification of industrial production in various regions has resulted in an accumulated pollution load that threatens aquatic biodiversity and the health of communities dependent on these water resources.

Based on a preliminary study of an online survey using the Google Form platform to the teachers and students at several junior high schools in East Lampung Regency, it was revealed that the implementation of practicums and the use of practicum instruments in Natural Sciences learning were ineffective. The data showed that 94.1% of students had practicum experience with topics such as air pollution (47.1%), water pollution (32.4%), and soil pollution (20.6%). However, students stated that teachers only conducted experiments in learning as much as 50%. During the practicum, teachers only used practicum tools such as bottles with filters filled with soil, paper, and simple water filtration. In fact, as many as 50% of students stated that they did not conduct experiments. The practicum tools used were not yet able to identify indicators of water pollution (Fitriani & Suryadi, 2019; Utami & Hidayat, 2020; Mulyani & Sari, 2021).

A needs analysis conducted with 14 science teachers at the junior high school level in East Lampung revealed that educators have implemented learning using laboratory tools for pollution topics, but have not yet used better laboratory tools such as automated laboratory tools. A significant finding was that 94.4% of teachers were unfamiliar with automated sensor technology such as the PH-4502C.

Several previous studies have been conducted, such as Arifin et al. (2020) study, which developed a mobile virtual laboratory for practical learning on water pollution. The results showed that the developed mobile virtual lab was excellent in all aspects. Futhermore, Destiansari et al. (2022) study developed a digital virtual laboratory-assisted practical worksheet on water pollution. The results showed that the developed worksheet was valid and categorized as good. Several studies have shown that the development of practical tools is still minimal. Previous studies tended to focus on developing a single measuring instrument or a theoretical approach to systems thinking, but none have integrated these two aspects into a comprehensive practical system. Therefore, this study aims to develop an integrated practical tool on the topic of water pollution, reviewed from the perspective of physics, chemistry, and biology, to train students' Systems Thinking Skills.

Method

This research is a research and development (R&D). The research stages consist of four stages, namely: define, design, develop, and disseminate. In the Define stage, a preliminary analysis was conducted to identify problems in learning water pollution topics, particularly related to students' low systems thinking skills. This stage included curriculum analysis, student characteristics analysis, and concept analysis.

In the Design stage, the initial prototype of the practicum device was developed, along with supporting instruments such as validation sheets, observation sheets, and systems thinking skills tests. The systems thinking instrument was constructed based on hierarchical levels (Level A, B, and C), adapted to measure students' ability to identify components, relationships, and dynamic interactions within water pollution systems.

In the Develop stage, the practicum device and instruments were validated by experts (material and media experts). After revision, a limited trial was conducted involving 32 students. Data collected included : Validation data from experts, Students' systems thinking test results (pretest and posttest), Observation of practicum implementation. The effectiveness of the practicum device was analyzed using the N-gain score to determine the improvement in students' systems thinking skills.

The product that will be produced from this research and development is a practical tool for water pollution. The 4D model can be presented as seen in Figure 1. The research flow in this study can be seen in Figure 2.

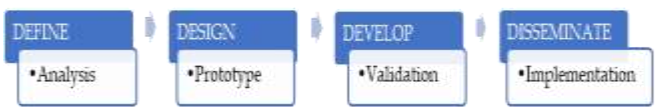

Figure 1. Research procedure using 4D model

The data collection techniques in this study used questionnaires, tests, and repertory grids. The questionnaires included a validation questionnaire for the practical tools by experts and a questionnaire for teacher responses regarding the suitability of the attractiveness, construction, and functionality of the water pollution practical tools. The score calculation for each item is as follows (Hake, 1998).

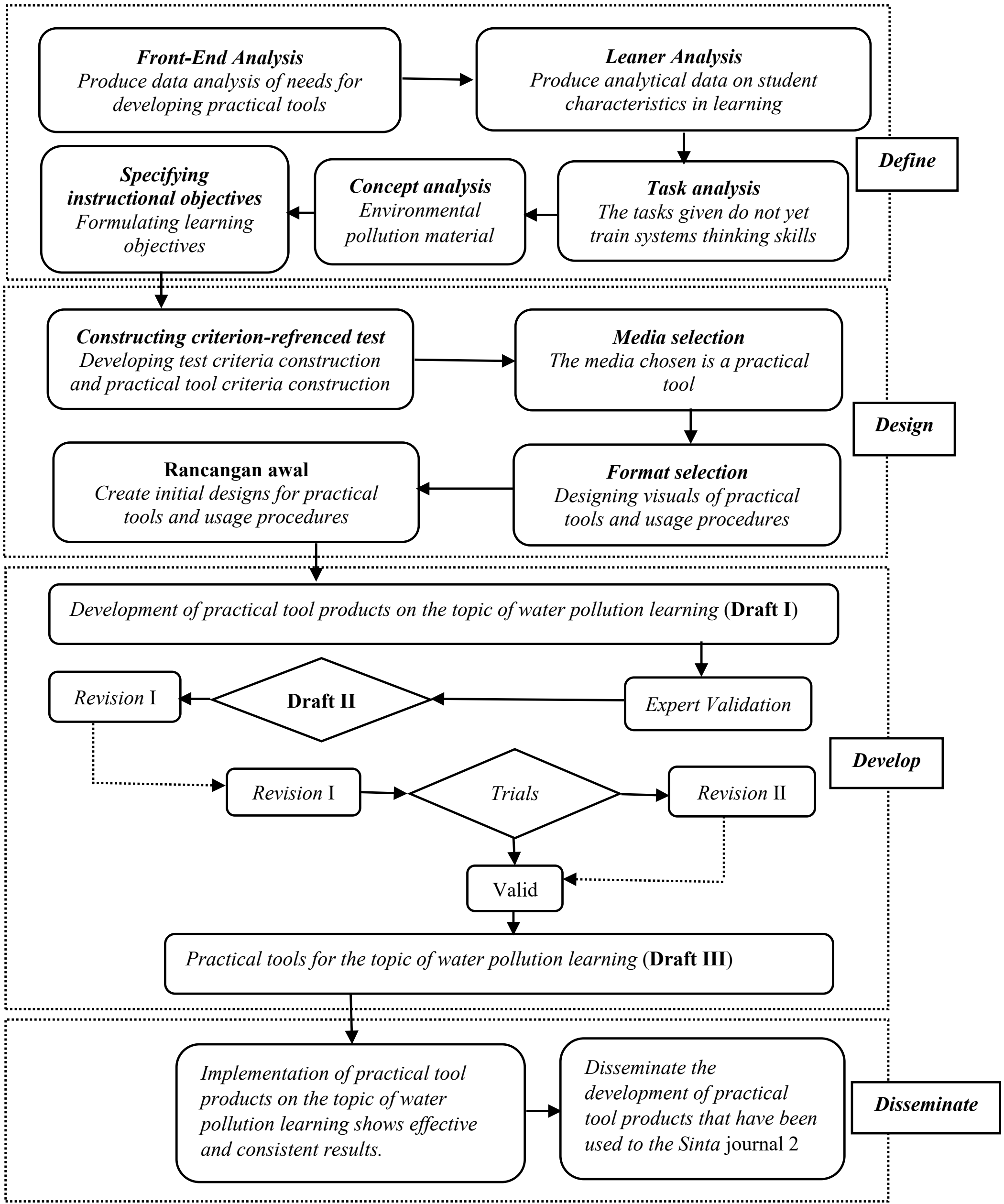

Figure 2. Research flow

$$\% \text{ Jin} = \frac{\sum \text{Ji}}{\text{N}} \times 100\% \quad (1)$$

Information:
% Jin = percentage of answer choice-i
∑Ji = number of respondents who answered answer-i
N = total number of respondents

The validity data analysis technique uses the following formula.

$$\% \text{ Xin} = \frac{\sum \text{S}}{\text{Smax}} \times 100\% \quad (2)$$

Information:
% Xin = percentage of respondents' answers to the questionnaire
∑S = total score of answers
Smax = maximum expected score

Result and Discussion

The results and discussion of the data obtained in the form of a questionnaire related to the development of practical tools on the topic of pollution are presented in Figure 3.

Based on Figure 3, the results of the teacher needs analysis in statement A1 indicate that 67% of teachers have implemented practicum-based learning and 33% have not. This shows that most teachers understand the importance of practicum activities. However, the existence of teachers who have not implemented practicums indicates limitations such as inadequate facilities, lack of skills in designing practicums, and limited time allocation, which can reduce opportunities for students to engage in meaningful learning.

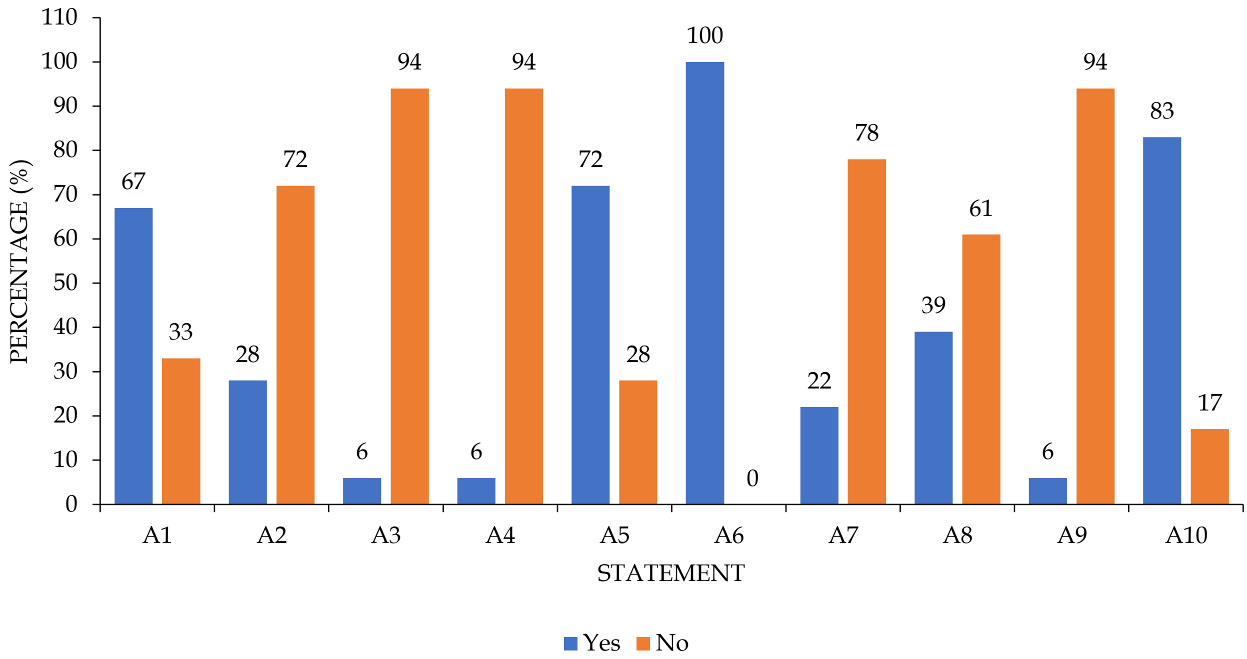

Figure 3. Result of teacher needs analysis

Information:

A1 : Teachers implement learning with practical material.

A2 : The teacher has used practical tools for classroom learning.

A3 : The practical equipment already uses a pH-4502C sensor.

A4 : The teacher uses practical tools that can be used to see water quality and see photosynthesis indicators.

A5 : Teachers are helped by the availability of practical tools integrated into the water pollution material.

A6 : Teachers use learning models in the learning process.

A7 : Teachers know systems thinking skills.

A8 : During the environmental pollution learning process, the teacher has equipped it with components that improve systems thinking skills.

A9 : Practical tools used in learning are able to train systems thinking.

A10 : Teachers agree with the development of practical tools to practice systems thinking.

Statement A2 shows that 28% of teachers have used practical tools, while 72% have not. This indicates that the implementation of practicum activities is still very limited. This condition suggests that learning is still dominated by theoretical approaches, so students have fewer opportunities to develop scientific and investigative skills. This finding is in line with previous studies stating that practical activities play an important role in improving students' understanding of science concepts (Hofstein & Lunetta, 2004).

In statement A3, 94% of teachers have not used the pH-4502C sensor and only 6% have used it. This shows that the use of digital sensor technology is still very low. This may be caused by limited access to technology, lack of training, and low teacher competence in using digital tools, which is in line with previous studies stating that teachers tend to rely on conventional tools (Hmelo-Silver, 2004; Astuti & Bhakti, 2018). As a result, learning has not optimally utilized technology to support accurate data analysis.

Statement A4 shows that 94% of teachers have not used tools to measure water quality and photosynthesis indicators. This indicates that learning has not yet integrated physical, chemical, and biological parameters comprehensively, even though this integration is essential in understanding water pollution systems holistically.

In statement A5, 72% of teachers stated that they are helped by the availability of integrated practicum tools. This shows that such tools can support the learning process. These tools provide a more contextual and concrete learning experience, allowing students to observe and analyze environmental phenomena directly, which is important in developing higher-order thinking skills.

Statement A6 shows that 100% of teachers use learning models. This is a strong foundation for implementing innovative learning approaches, including the integration of practicum activities and systems thinking, because learning models can guide structured scientific investigations.

In statement A7, 78% of teachers do not know systems thinking skills. This indicates a significant gap in the development of higher-order thinking skills, where students are not yet trained to understand relationships and interactions within a system, especially in environmental topics. Systems thinking is essential in helping students understand complex systems and interconnections in science learning (Kurniawan & Astuti, 2019; Nugroho & Suyanto, 2020).

Statement A8 shows that 61% of teachers have not integrated systems thinking components into learning. This is closely related to the lack of teacher understanding of systems thinking, resulting in learning that is still fragmented and not yet directing students to think holistically and systemically.

In statement A9, 94% of teachers stated that existing practicum tools cannot train systems thinking skills. This finding reinforces that current learning tools are not designed to support systems-based analysis, so students are not trained to identify relationships, interactions, and feedback within environmental systems. This is consistent with previous research which emphasizes that appropriate learning tools are needed to support higher-order thinking skills, including systems thinking (Rahmawati & Ridwan, 2017).

In statement A10, 83% of teachers agree with the development of practicum tools to train systems thinking. This shows a strong need for innovation in learning tools, especially those that can facilitate students in identifying system components, understanding cause-and-effect relationships, and analyzing interactions within water pollution systems.

Overall, these findings indicate a gap between current learning practices and the need to develop systems thinking skills. Therefore, the development of water pollution practicum tools based on physical, chemical, and biological parameters is a relevant and necessary solution to support more meaningful and systemic science learning.

Conclusion

Based on the results of the study, there is a gap between current learning practices and the need to develop students' systems thinking skills. Existing practicum tools are not yet able to support these skills effectively. Therefore, the development of water pollution practicum tools based on physical, chemical, and biological parameters is needed and has the potential to support the improvement of students' systems thinking skills in science learning.

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Author Contributions
The author contributed to the design, implementation, data analysis, and writing of this research related to the development of systems thinking-based practicum tools on environmental pollution topics.

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Conflicts of Interest
No conflict of interest.

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