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Development of a Research-Based Digital Teaching Supplement on Heavy Metal Pollution to Equip Junior High School Students with Digital Literacy Skills

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Abstract

Heavy metal pollution is an environmental problem that directly impacts human health and the sustainability of aquatic ecosystems. Research indicates that the issue of heavy metal pollution can be used as a contextual learning resource to foster students' digital literacy skills and environmental awareness. Preliminary observations at SMP Negeri 1 Boja revealed that students' digital literacy skills remain relatively low, indicating the need for innovative learning resources to enhance these competencies. This study aims to develop a research-based digital teaching supplement on heavy metal pollution to equip junior high school students with digital literacy skills. The research employed the ADDIE model, comprising the stages of analysis, design, development, implementation, and evaluation. The study involved eighth-grade students at SMP Negeri 1 Boja during the 2024/2025 academic year. Data analysis used descriptive statistics to assess validity and practicality, as well as percentage achievement analysis to evaluate students' digital literacy. The results show that: (1) material expert validation scored 91.54% (very feasible) and media expert validation scored 93.07% (very feasible), (2) student responses indicated a practicality score of 93.06% (very practical), and (3) students' digital literacy averaged 85.74% (very good) across the five aspects: accessing (90.00%), selecting (83.97%), understanding (90.15%), evaluating (80.44%), and producing (84.12%). These findings demonstrate that the developed research-based digital teaching supplement is highly feasible, highly practical, and effective in equipping students with strong digital literacy skills.

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INTRODUCTION

Heavy metal pollution has emerged as one of the most serious environmental issues affecting aquatic ecosystems and human health worldwide. Heavy metals such as mercury (Hg), lead (Pb), cadmium (Cd), and arsenic (As) are non-biodegradable, persist in the environment, and accumulate through the food chain, leading to toxic effects on living organisms (Ali et al., 2019; Khan et al., 2021). In Indonesia, cases of heavy metal contamination in rivers, coastal areas, and estuaries have been widely reported, primarily due to industrial waste disposal, mining activities, and agricultural runoff (Palar, 2021). This environmental problem is not only a threat to biodiversity but also poses a significant challenge to community health and sustainable development goals.

Environmental issues such as heavy metal pollution can serve as contextual learning resources in science education (Welerubun, et al., 2022; Fajeriadi & Irhasyuarna, 2021). Contextual learning allows students to relate scientific concepts to real-life phenomena, fostering critical thinking and environmental awareness (Fauziah et al., 2020). Moreover, integrating real-world environmental cases into learning materials can enhance students' digital literacy, a crucial competency in the 21st century (Ng, 2012). Digital literacy, which encompasses the abilities to access, evaluate, and produce information using digital technology, is essential for students to navigate information-rich environments effectively (UNESCO, 2018).

However, preliminary observations at SMP Negeri 1 Boja revealed that students' digital literacy skills remain relatively low, particularly in evaluating and producing information from digital sources. Existing learning materials are often text-heavy, lack interactive features, and do not adequately integrate current environmental issues into the curriculum. Previous studies indicate that interactive digital teaching materials can significantly improve students' engagement, comprehension, and critical thinking skills (Prasetyo & Sari, 2021; Wahyuni et al., 2023). Yet, there is limited research focusing on the development of digital learning supplements based on empirical environmental research, specifically heavy metal pollution, to foster digital literacy among junior high school students (Kuswandi, et al., 2025; Lo, 2024; Husamah, et al., 2025).

In response to this gap, this study aims to develop a research-based digital learning supplement on heavy metal pollution in aquatic environments to enhance junior high school students' digital literacy. The supplement is designed in the form of an interactive e-booklet, integrating multimedia elements such as text, images, videos, and educational games to support the five indicators of digital literacy: accessing, selecting, understanding, evaluating, and producing information (Gultom, et al., 2022; Oktariani, 2024; Abu-Ras, et al., 2025).

METHOD

This study employed a Research and Development (R&D) design using the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). The ADDIE model was selected because it offers a systematic framework for developing instructional products and allows for iterative refinement based on expert validation and user feedback.

The research was conducted at SMP Negeri 1 Boja during the 2024/2025 academic year. The participants consisted of 30 eighth-grade students as the trial subjects. Additionally, three material experts (two university lecturers and one science teacher) and three media experts (two university lecturers and one science teacher) participated in the validation process. The experts were selected based on their expertise in science education, instructional media, and environmental studies.

Three instruments were used in this study: (1) a material validation questionnaire, (2) a media validation questionnaire, and (3) student response and digital literacy questionnaires. The validation instruments for both material and media experts were adapted from the Badan Standar Nasional Pendidikan (BSNP) criteria and modified according to the needs of the digital supplement. Each instrument used a Likert scale ranging from 1 (very poor) to 5 (very good).

The digital literacy questionnaire was adapted from UNESCO's (2018) digital literacy framework, encompassing five indicators: accessing, selecting, understanding, evaluating, and producing information. The questionnaire consisted of positive and negative statements to measure each indicator comprehensively. In the analysis stage, needs analysis was conducted through classroom observations and interviews with teachers to identify students' digital literacy levels and learning challenges regarding heavy metal pollution. In the design stage, the structure and layout of the digital supplement were planned, including the integration of multimedia elements

such as text, images, videos, games, and interactive links. The content was based on resarch findings related to heavy metal pollution in aquatic environments, contextualized for junior high school science learning.

During the development stage, the digital supplement was created using BookCreator, integrating research-based content, multimedia resources, and interactive features aligned with digital literacy indicators. The product was then validated by material and media experts (Astuti, et al., 2020). In the implementation stage, the validated digital supplement was tested with the target group of students during science lessons. Students engaged with the supplement in both classroom and independent learning contexts. Finally, in the evaluation stage, feedback from students and experts was analyzed. Data from the questionnaires were processed to determine the validity, practicality, and impact of the digital supplement on students' digital literacy (Chang & Kuo, 2025).

Quantitative data from expert validations and student responses were analyzed using descriptive statistics to determine average scores and percentage categories (Arikunto, 2014). The criteria for interpretation followed the BSNP classification: 85–100% (very valid/very practical), 70–84% (valid/practical), and <70% (less valid/less practical).

RESULT AND DISCUSSION

The results of the validation by three subject matter experts, consisting of two lecturers and one junior high school teacher, are presented in Table 4.1. The validation covered five aspects: introduction, content/material, material presentation, language, and characteristics. The overall mean score was 97.8%, categorized as very valid, with the decision of "feasible to use with minor revisions." In the introduction aspect, which includes the clarity of learning instructions and the clarity of learning objectives and indicators, the percentage score reached 95.8% (very valid). This indicates that the digital supplement provides well-structured guidance for students, aligning with the learning outcomes. The content/material aspect, which includes the completeness of material, accuracy of definitions and concepts, accuracy of references, and ease of understanding, also received a score of 95.8% (very valid). This aligns with previous research by Hidayati et al. (2020), which emphasized that well-structured content with accurate references increases the reliability of digital learning resources.

The material presentation aspect, including suitability with students' cognitive development and consistency of presentation, achieved a score of 95.8% (very valid). The language aspect obtained a perfect score of 100%, indicating compliance with the rules of the Indonesian language, clarity, and avoidance of ambiguity. The characteristic aspect, which integrates research findings on heavy metal pollution and links them to the learning objectives, also received a perfect score of 100%. Similar to the findings of Fitriyani et al. (2021), integrating real research data into learning materials enhances contextual learning and student engagement.

Validation by two media experts and one teacher focused on five aspects: graphics, media design, language, usability, and digital literacy reinforcement (Lafifa & Rosana, 2023). The average score was 97.2% (very valid). The graphics aspect, which includes font variety, layout, proportionality, and image quality, achieved 92.7% (very valid), indicating strong visual appeal and readability. The media design and language aspects both received a perfect score of 100%, demonstrating effective and attractive design elements as well as clarity in communication. The usability aspect also scored 100%, suggesting that the supplement is easy to operate and accessible to students. The digital literacy reinforcement aspect, also with a perfect score, shows that the material effectively guides students in accessing, evaluating, and producing digital content. This finding supports the conclusion of Widodo et al. (2019), who noted that media design quality significantly impacts user engagement and comprehension.

Student responses to the practicality of the digital supplement were measured across three aspects: ease of use (88.36%), attractiveness of presentation (90.29%), and usefulness (91.18%). The overall score was 89.94%, categorized as very practical. Students expressed enthusiasm for learning science with the digital supplement and suggested similar materials be applied in other subjects. They highlighted its engaging features, ease of navigation, and variety of interactive elements such as images and educational games. These results are consistent with Nugroho et al. (2020), who found that interactive digital learning materials enhance student motivation and active participation. Furthermore, the positive student feedback reflects the principle that practicality is closely linked to user satisfaction and continued usage (Jumadi et al., 2018).

The digital literacy assessment revealed an average score of 85.74% (very good), with

the highest achievement in the understanding aspect (90.15%) and the lowest in the evaluating aspect (80.44%). The access (90.00%), selection (83.97%), and production (84.12%) aspects also scored in the very good category. These findings indicate that the digital supplement successfully trains and equips students with strong digital literacy skills, particularly in accessing and understanding information. However, the relatively lower score in evaluation skills suggests that students require more practice in critically assessing the credibility and accuracy of online information (Kohnen, et al., 2021). This aligns with research by Listiani et al. (2022), which emphasizes that evaluation is the most challenging aspect of digital literacy for students and requires structured learning experiences. Overall, the integration of heavy metal pollution research into the digital supplement proved effective in fostering both content mastery and digital literacy skills, supporting the arguments of Rahmawati et al. (2021) that contextual, research-based learning materials improve environmental awareness and 21st century competencies.

CONCLUSION

This study developed a research-based digital learning supplement on heavy metal pollution designed to equip junior high school students with strong digital literacy skills. The results demonstrated that the product achieved an excellent level of feasibility, with material experts rating it at 97.8% and media experts at 97.2%, both categorized as "very valid" and deemed suitable for use with minor revisions. The practicality evaluation showed a score of 89.94%, indicating that the supplement was "very practical" in terms of ease of use, presentation appeal, and usefulness. Furthermore, the post-use digital literacy assessment revealed an average score of 85.74%, categorized as "very good," with all five indicators accessing, selecting, understanding, evaluating, and producing information meeting high competency levels. These findings indicate that the developed digital supplement is not only valid and practical but also proven to effectively train and equip students with strong digital literacy competencies. The integration of authentic research on heavy metal pollution into the learning materials provided a contextual and relevant approach that encouraged critical thinking, creativity, and environmental awareness. Future research could focus on scaling the implementation to larger and more diverse student populations, as well as integrating more interactive features such as augmented reality or gamified learning elements to further enhance engagement and learning outcomes.

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