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Development of a Board Game on Water Ecosystem Materials Oriented toward Socio-Scientific Issues and Critical Thinking

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ABSTRACT

This study aims to develop and evaluate a board game–based learning media on water ecosystem content oriented toward socio-scientific issues (SSI) and critical thinking skills. The study employed a Research and Development (R&D) approach adapted from the 4D model, consisting of three stages: define, design, and develop. The product was validated by six experts (three content experts and three media experts) and tested through a limited trial involving 30 seventh-grade students. The results showed that the media achieved a validation score of 94.44% from media experts and 91.67% from content experts, both categorized as "very feasible." Student responses yielded an average score of 79.39%, indicating that the media is "very practical." These findings suggest that the developed board game is effective in terms of design, usability, and instructional relevance. The integration of SSI within the game scenarios enables students to engage with real-world environmental issues, thereby promoting critical thinking through processes of analysis, evaluation, and decision-making. This study contributes to science education by offering an innovative learning media that integrates content knowledge, socio-scientific contexts, and higher-order thinking skills within a game-based framework. Overall, the developed board game demonstrates strong potential as an interactive and meaningful learning tool in science education. Future research is recommended to investigate its effectiveness in improving students' critical thinking skills through experimental studies and broader implementation.

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Introduction

Science education in the modern era requires students not only to acquire factual knowledge but also to develop higher-order thinking skills, particularly critical thinking (Ridho et al., 2020). As a core competency of the 21st century, critical thinking enables students to analyze information, evaluate problems, and make well-reasoned decisions in diverse real-life contexts (Dusturi et al., 2024). Within science learning, this skill is essential for facilitating students' understanding of scientific concepts and their ability to relate these concepts to real-world phenomena (Ambarwati & Fauziah, 2024). One topic that particularly demands strong critical thinking skills is water ecosystems (Sigit et al., 2024). This topic involves complex interactions between biotic and abiotic components and requires students to examine how human activities affect environmental balance (Wijaya, 2024). Mastery of this content requires

students to analyze causal relationships, evaluate environmental issues, and draw logical conclusions (Septiningrum et al., 2021). Therefore, effective science instruction should actively engage students in the analysis of authentic environmental problems (Budinarianti & Susiyawati, 2024).

Despite its importance, the implementation of such learning practices remains limited. Preliminary observations and interviews with science teachers at MTs NU Miftahul Ulum Loram Kulon Kudus indicate that instruction has not yet been optimally conducted. The learning media used in the classroom are still limited to textbooks and student worksheets, while instructional tools used by teachers remain conventional (Noor Sri Asih, personal communication, Oktober 2025). Learning media are still predominantly limited to textbooks and student worksheets, and teaching practices remain largely conventional. The integration of interactive learning media, such as educational games, has not been widely implemented. Consequently, students tend to be passive and experience difficulties in developing a deep conceptual understanding (Nora'in et al., 2025). Furthermore, students continue to face challenges in analyzing environmental phenomena and constructing logical scientific arguments (Heriyati, 2017).

Previous studies have demonstrated that interactive learning media can significantly enhance student engagement and improve conceptual understanding (Hosnia et al., 2025). Among these, board games represent a promising instructional media in science education (Putri & Nisa, 2024), as they provide interactive and enjoyable learning experiences while fostering collaboration and active participation (Boimau & Duka, 2024). Game-based learning also allows students to explore scientific concepts in more meaningful and engaging way (Adhinda Mutiara Janah, 2025). However, most existing studies have primarily focused on engagement and motivation, with limited emphasis on integrating higher-order thinking skills, particularly critical thinking, within the game design.

In addition to interactive media, the integration of the Socio-Scientific Issues (SSI) approach has been recognized as a crucial component of science education (Sari et al., 2025). SSI-based learning connects scientific concepts with real-world social problems, requiring students to analyze scientific evidence while considering ethical and societal perspectives (Nora'in et al., 2025). This approach has been shown to promote critical thinking by engaging students in evaluating complex, real-life issues and making informed decisions (Nanjundaswamy et al., 2021) For example, the uncontrolled proliferation of water hyacinth in Rawa Pening Lake, Semarang, represents a relevant socio-scientific issue (Pebrianti et al., 2024). This phenomenon has led to environmental degradation and social challenges, including declining water quality and disruption to local livelihood (Agus, personal communication, Mei 2025). This phenomenon illustrates the relationship between human activities and ecosystem balance (Ramadhani & Susiyawati, 2025). Analyzing such issues enables students to understand the interconnection between human activities and ecosystem balance while developing their ability to propose solutions that consider both ecological and social dimensions (Mondaylisa & Wilujeng, n.d.).

Although prior research has highlighted the benefits of board games and SSI-based approaches independently, there remains a lack of studies that integrate both within a single instructional media, particularly in the context of water ecosystem learning. Moreover, limited

attention has been given to designing game-based learning that explicitly targets the development of critical thinking skills through socio-scientific contexts. This gap indicates the need for innovative instructional media that combine interactive learning, real-world problem contexts, and higher-order thinking skill development (Siregar & Ananda, 2023). Therefore, this study aims to develop a board game–based learning media on water ecosystem content oriented toward socio-scientific issues and critical thinking (Yunarti et al., 2022) This study contributes to the field by integrating SSI and critical thinking into a game-based learning design, thereby offering a novel approach to science instruction. The developed media are expected to be interactive, feasible, and practical, while also supporting meaningful learning and fostering students' critical thinking skills.

Method

This study employed a Research and Development (R&D) approach to develop a board game–based learning media on water ecosystem content oriented toward socio-scientific issues (SSI) and critical thinking skills (Arkadiantika et al., 2020). The development model was adapted from the 4D model proposed by Thiagarajan, which originally consists of four stages: define, design, develop, and disseminate. However, in this study, the model was modified into three stages—define, design, and develop—by excluding the dissemination stage.(Febriani et al., 2020)

The **define stage** aimed to analyze learning needs through literature review, curriculum analysis, and analysis of students' characteristics. This stage was conducted to identify problems in science learning, particularly in the water ecosystem topic, and to determine the need for appropriate instructional media (Azzahrah, 2023).

The **design stage** involved the development of the board game prototype, including the game board, phenomenon-action cards, mystery cards, certificate cards, and game rules. At this stage, instructional content was systematically organized by integrating water ecosystem concepts with the SSI approach and indicators of critical thinking.

The **develop stage** aimed to produce a feasible learning media product through expert validation and limited field testing. The validation process involved six experts, comprising three content experts and three media experts, who evaluated the feasibility of the developed product based on predetermined criteria(Astuti et al., 2017).

This study was conducted at MTs NU Miftahul Ulum Loram Kulon Kudus, involving 30 seventh-grade students who participated in the limited trial. The research instruments consisted of expert validation questionnaires and student response questionnaires. The expert validation questionnaire was used to assess the feasibility of the learning media, while the student response questionnaire was employed to evaluate its practicality.

To ensure **content validity**, the validation instruments were reviewed by experts in science education and instructional media. The validation criteria covered aspects such as content accuracy, relevance to the curriculum, clarity of instructions, visual design, and alignment with SSI and critical thinking indicators. Data obtained from expert validation and student responses were analyzed using descriptive quantitative techniques through percentage calculations. The percentage scores were calculated using the formula:

$$P = f / N \times 100\%$$

where *P* represents the percentage score, *f* is the total score obtained, and *N* is the maximum possible score, to determine the overall quality of the developed board game–based learning media. The resulting percentages were then categorized according to established feasibility and practicality criteria.

Table 1. Criteria for Feasibility and Practicality (Febriana, 2014)

Score	Category
76% - 100%	very feasible/ very practice
56 % - 75 %	feasible/ practice
40 % - 55 %	sufficiently feasible/ sufficiently pratice
<40 %	Not feasible/ not practice

Media is categorized as theoretically feasible and practice if the percentage reaches 56% - 75%, indicating that the media has fulfilled most of the established validity criteria.

Results and Discussion

This study resulted in the development of a board game–based learning media on water ecosystem content oriented toward socio-scientific issues (SSI) and critical thinking skills (Lamote, 2023). In the **define stage**, a needs analysis was conducted through a literature review, curriculum analysis, and interviews with science teachers at MTs NU Miftahul Ulum Loram Kulon Kudus. The findings revealed that the learning media used in the classroom were primarily limited to textbooks and student worksheets, leading to predominantly conventional instructional practices that did not optimally engage students. Furthermore, students experienced difficulties in analyzing environmental phenomena related to water ecosystem concepts (Siregar & Ananda, 2023). These findings highlight the need for more interactive and context-based learning media to support students' understanding and critical thinking skills.

In the **design stage**, the board game–based learning media was systematically developed by incorporating several key components. These included a game board representing the water ecosystem, phenomenon-action cards containing socio-scientific issues, mystery cards presenting game-based challenges, certificate cards indicating ownership of specific areas within the game, and tokens used as in-game currency. The design was intended to create an interactive and engaging learning environment, enabling students to explore water ecosystem concepts through meaningful game-based activities. The integration of socio-scientific issues within the game scenarios was specifically intended to stimulate students' critical thinking by encouraging them to analyze real-world environmental problems and propose reasoned solutions. The visual appearance of the developed board game–based learning media is presented in **Figure 1**.

Figure 1. Board Game Learning Media on Water Ecosystem Material

The developed board game integrates socio-scientific issues (SSI) and critical thinking through the presentation of environmental phenomena derived from the context of Rawa Pening Lake. These issues are embedded in *phenomenon-action cards*, which present authentic real-world problems accompanied by alternative actions that players must evaluate and select. The inclusion of contextual and relevant environmental issues is intended to promote a deeper and more meaningful understanding of aquatic ecosystem concepts (Dusturi, et al., 2024). This design is grounded in constructivist learning theory, which emphasizes that knowledge is actively constructed by learners through engagement with real-world contexts and problem-solving activities. For instance, one of the phenomenon cards presented in Figure 1 highlights the issue of the uncontrolled proliferation of water hyacinth in Rawa Pening Lake. The card includes contextual data indicating that approximately 30% of the lake's surface is covered by water hyacinth, leading to disruptions in fishing activities and ecological imbalance. This phenomenon not only reflects key scientific concepts—such as interactions between biotic and abiotic components and the dynamics of aquatic plant populations—but also illustrates the broader socio-economic consequences for local communities. Therefore, it represents a well-contextualized SSI problem that connects scientific understanding with real-life implications. (Central Java Governance, 2017). From a critical thinking perspective, the inclusion of

quantitative data requires students to engage in interpretation and analysis of scientific information. According to Facione's critical thinking framework, essential skills include interpretation, analysis, evaluation, and inference, all of which are activated when students are confronted with complex, data-driven scenarios (Haryanti, et al., 2024). In this context, students are not only required to understand the presented information but also to evaluate its implications and consider appropriate solutions. This finding is consistent with previous studies indicating that SSI-based learning environments can effectively foster higher-order thinking skills by situating learning within authentic problem contexts (Nanjundaswamy et al., 2021).

Another example is the "fish cages" scenario, which introduces the issue of invasive Red Devil fish in aquaculture environments. This scenario is closely related to ecological concepts such as invasive species, interspecific interactions, and food web dynamics. At the same time, it highlights socio-economic impacts, particularly the financial losses experienced by fish farmers due to predation. Such scenarios demonstrate that environmental problems are inherently interdisciplinary, requiring not only scientific analysis but also consideration of social and economic dimensions (Budinarianti & Susiyawati, 2024). This aligns with the fundamental principles of SSI-based learning, which emphasize the integration of scientific knowledge with societal contexts.

Furthermore, the alternative actions provided in each card are explicitly designed to facilitate decision-making processes, which are central to critical thinking. For example, in the Rawa Pening scenario, students are presented with three possible actions: (1) regularly removing water hyacinth, (2) allowing it to grow unchecked, and (3) processing water hyacinth into handicrafts to reduce its abundance. These options require students to evaluate each alternative based on logical reasoning, feasibility, and potential impact. This process aligns with Ennis's framework of critical thinking, which emphasizes the ability to make rational decisions based on relevant evidence and sound reasoning (Elfitriyah, et al., 2025). Selecting the third option as the most appropriate solution reflects students' ability to integrate ecological and socio-economic considerations, demonstrating evaluative and decision-making skills. This indicates that students are not only engaging with the content at a conceptual level but are also applying critical thinking to solve real-world problems. These findings are in line with prior research suggesting that game-based learning integrated with SSI can enhance students' critical thinking and decision-making abilities (Sari et al., 2025). However, unlike previous studies that often examine SSI or game-based learning separately, this study integrates both approaches within a single instructional media, thereby offering a more comprehensive learning experience.

The effectiveness of integrating SSI and critical thinking within the board game is further supported by expert validation results, which indicate that the developed media meets high standards of feasibility and pedagogical relevance. This suggests that the board game not only functions as an engaging learning tool but also as an effective media for fostering higher-order thinking skills in science education. The develop stage was carried out by conducting expert validation and limited trials involving students. The validation process was conducted by three media experts and three material experts. The results of media expert validation are presented in **Table 2.**

Table 2. Media Expert Validation Result

No	Aspect	Validator 1	Validator 2	Validator 3	Average
1	Media design	91,67%	100,00%	91,67%	94,44%
2	Display quality	100,00%	100,00%	91,67%	97,22%
3	Accessibility	100,00%	75,00%	100,00%	91,67%
		Average			94,44%
		Category			"Very Feasible"

Based on Table 2, the average percentage obtained from media expert validation reached 94.44%, which falls into the "very feasible" category. This result indicates that the developed board game–based learning media demonstrates an appropriate design, an attractive visual appearance, and ease of use in instructional activities. These aspects are essential in supporting effective learning, as well-designed instructional media can enhance student engagement, improve usability, and facilitate conceptual understanding. The high validation score also reflects that the media meets key quality indicators, including layout clarity, visual consistency, readability, and the suitability of game components for classroom implementation. This finding is consistent with previous studies, which suggest that interactive and visually appealing learning media contribute significantly to increasing students' motivation and participation in science learning (Hosnia et al., 2025).

In addition to media validation, the developed product was also evaluated by content experts to assess the alignment of the learning materials with water ecosystem concepts and the intended learning objectives (Boimau & Duka, 2024). This validation ensures that the instructional content is scientifically accurate, relevant to the curriculum, and pedagogically appropriate for students' cognitive levels. The involvement of content experts is particularly important to ensure that the integration of socio-scientific issues (SSI) and critical thinking indicators is conceptually sound and supports meaningful learning.

The results of the content expert validation are presented in Table 3, which further demonstrate the overall feasibility of the developed learning media in terms of content quality and instructional relevance.

Table 3. Content Expert Validation Result

No	Aspect	Validator 1	Validator 2	Validator 3	Average
1	Content suitability	93,75%	75,00%	93,75%	87,50%
2	Concept accuracy	100,00%	87,50%	100,00%	95,83%
3	Learning objective alignment	100,00%	75,00%	100,00%	91,67%
		Average			91,67%
		Category			"Very Feasible"

Based on Table 3, the average percentage obtained from content expert validation reached 91.67%, which is categorized as "very feasible." This result indicates that the learning materials embedded in the board game are accurate, relevant, and aligned with the intended learning objectives (Purnamawati et al., 2025). Furthermore, the high validation score suggests that the integration of water ecosystem concepts with socio-scientific issues (SSI) and critical thinking indicators has been appropriately designed to support meaningful learning.

Following the validation and product revision process, the board game–based learning media was implemented in a limited trial involving 30 seventh-grade students at MTs NU Miftahul Ulum Loram Kulon Kudus. The purpose of this trial was to evaluate the practicality of the developed learning media in real classroom settings. The results of the student response questionnaire, presented in Table 4, indicate the level of practicality of the media based on students' perceptions. These responses provide important insights into the usability, attractiveness, and effectiveness of the board game in facilitating learning activities.

Table 4. Student Response Results

No	Aspect	Presentage (%)	Category
1	Accessibility	79,79%	Very Practical
2	Attractiveness of media	77,83%	Very Practical
3	Learning motivation	80,56%	Very Practical
	Average		79,39%
	Category		"Very Practical"

Based on Table 4, the average percentage of student responses reached 79.39%, which is categorized as "very practical." This finding indicates that the board game–based learning media is easy to use, engaging, and effective in enhancing student participation during the learning process. The practicality assessment covered three main aspects: visual display, ease of use, and perceived benefits of the media.

First, the practicality of the media display obtained a percentage of 80.56%, indicating that the visual design successfully attracted students' attention and interest. Second, the ease-of-use aspect achieved an average score of 79.79%, suggesting that the game mechanics were clearly understood and could be effectively operated by students. Third, the perceived benefits of the media reached an average score of 77.83%, demonstrating that students found the board game helpful in understanding water ecosystem concepts, particularly through engagement with socio-scientific issues (SSI) presented in the form of dilemmas. These findings are consistent with the primary objective of media development, which is to create meaningful and applicable learning experiences (Muzakky, 2025).

The use of board game–based media in science learning provides a more interactive and student-centered learning experience compared to conventional instructional approaches (Adhinda Mutiara Janah, 2025) Through gameplay, students are not only introduced to water ecosystem concepts but are also exposed to real-world environmental issues framed within socio-scientific contexts (Nursirwan et al., 2023). This learning situation encourages students

to analyze problems, evaluate alternative solutions, and make reasoned decisions—core components of critical thinking(Maharani, 2024). These findings are in line with previous studies indicating that the integration of game-based learning and SSI can effectively foster higher-order thinking skills and active learning engagement.

Therefore, the development of board game–based learning media oriented toward socio-scientific issues and critical thinking offers a promising innovation in science education, particularly for water ecosystem topics. Theoretically, this study contributes to the literature on science learning media by integrating three key components—aquatic ecosystems, socio-scientific issues, and critical thinking—within a single instructional design. This integrated model may serve as a reference for future development of game-based learning media that emphasize not only content mastery but also higher-order thinking skills.

Practically, the developed board game can be utilized by teachers as an alternative interactive and contextual learning media. It supports the delivery of complex scientific concepts in a more accessible manner while promoting active student participation in the classroom. Furthermore, the use of this media contributes to the development of 21st-century skills, including critical thinking, communication, collaboration, and decision-making based on real-world issues. Through engagement with SSI scenarios, students are encouraged to consider multiple perspectives when addressing environmental problems.

Despite its contributions, this study has several limitations. First, in terms of content coverage, the board game is limited to the topic of aquatic ecosystems and does not encompass the full range of science subjects. Therefore, its application to other topics requires further adaptation and development. Second, regarding the depth of socio-scientific issues, the problems presented in the game are relatively simplified to align with the game mechanics and students' cognitive levels. As a result, the complexity of real-world issues may not be fully represented. Third, this study did not include a direct measurement of students' critical thinking skills after the implementation of the board game. Future research is therefore recommended to develop valid and reliable assessment instruments to comprehensively measure critical thinking outcomes.

Conclusion

This study developed and validated a board game–based learning media on water ecosystem content oriented toward socio-scientific issues (SSI) and critical thinking skills. The findings demonstrate that the developed media is both feasible and practical, as evidenced by high validation scores from media experts (94.44%) and content experts (91.67%), as well as positive student responses (79.39%). These results indicate that the board game meets key criteria in terms of design quality, content accuracy, usability, and instructional relevance. The integration of SSI within game-based learning effectively situates scientific concepts in real-world contexts, enabling students to engage in meaningful learning experiences. Through exposure to authentic environmental problems and decision-making scenarios, students are encouraged to interpret data, analyze issues, evaluate alternative solutions, and make reasoned decisions. This confirms the potential of the developed media to support the development of critical thinking skills, which are essential for 21st-century learning. This study contributes theoretically by proposing an

integrated instructional model that combines aquatic ecosystem content, socio-scientific issues, and critical thinking within a game-based learning environment. Practically, the developed board game offers an innovative and engaging alternative for science instruction, supporting teachers in delivering complex material while fostering active student participation. However, this study is limited to a specific topic and does not directly measure students' critical thinking outcomes. Future research is recommended to expand the application of this media to other science topics and to employ experimental designs with validated assessment instruments to examine its effectiveness in improving critical thinking skills.

Credit Authorship Contribution Statement

Widyaningrum, Sephiya: Formal analysis, Writing – original draft, Resources,, Data curation, and Visualization. **Laelasari, Iseu**: Writing – review & editing, Supervision, Validation. Conceptualization, and Methodology,

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