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Integrating 21st-century skills into a biology instructional module on ecosystems for tenth-grade learners

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ABSTRACT

The growing need for educational resources that integrate biology content with 21st-century skills calls for innovative, context-based learning modules. This study aims to develop a biology module for grade X students focused on ecosystem topics, incorporating four key 21st-century skills: critical thinking, creativity, communication, and collaboration. The content covers ecosystem components, energy flow, and biogeochemical cycles. Using a Research and Development approach with the 4D model (Define, Design, Develop, Disseminate), data were collected through teacher interviews, student questionnaires, expert appraisal, and assessments of students' critical and creative thinking. Expert appraisal, which included assessments of learning media, ecosystem material, and 21st-century skills, rated the module as highly valid. The evaluation of practicality conducted by both educators and learners indicates that this module is highly practical and straightforward to incorporate into educational activities. Effectiveness testing through pre- and post-tests showed a significant improvement in critical and creative thinking, with an N-Gain high category. These results indicate that the module is effective and suitable for classroom use. However, collaboration and communication were not comprehensively assessed. Therefore, it is recommended that teachers enhance module implementation with activities such as group discussions and presentations to develop these essential competencies further.

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ABSTRAK

Kebutuhan akan sumber daya pendidikan yang mengintegrasikan konten biologi dengan keterampilan abad ke-21 membutuhkan modul pembelajaran yang inovatif dan berbasis konteks. Penelitian ini bertujuan untuk mengembangkan modul biologi untuk peserta didik kelas X yang berfokus pada topik ekosistem, yang menggabungkan empat keterampilan utama abad ke-21: berpikir kritis, kreativitas, komunikasi, dan kolaborasi. Materi yang disajikan meliputi komponen ekosistem, aliran energi, dan siklus biogeokimia. Menggunakan pendekatan Penelitian dan Pengembangan dengan model 4D (Define, Design, Develop, Disseminate), data dikumpulkan melalui wawancara guru, kuesioner peserta didik, validasi ahli, dan penilaian pemikiran kritis dan kreatif peserta didik. Hasil evaluasi ahli yang meliputi media pembelajaran, konten ekosistem, dan keterampilan abad ke-21 menilai modul ini sangat valid. Penilaian kepraktisan dari guru dan peserta didik menunjukkan bahwa modul ini sangat praktis dan mudah diimplementasikan dalam kegiatan pembelajaran. Uji efektivitas melalui pre-test dan post-test menunjukkan adanya peningkatan yang signifikan pada kemampuan berpikir kritis dan kreatif, dengan nilai N-Gain kategori tinggi. Hasil ini menunjukkan bahwa modul ini efektif dan sesuai untuk digunakan di kelas. Namun, kolaborasi dan komunikasi tidak dinilai secara komprehensif. Oleh karena itu, disarankan agar guru meningkatkan implementasi modul dengan kegiatan seperti diskusi kelompok dan presentasi untuk lebih mengembangkan kompetensi esensial ini.

Kata Kunci: *keterampilan abad-21; materi ekosistem; pengembangan modul*

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INTRODUCTION

Biology education plays a significant role in shaping students' comprehension of the environment, particularly concerning ecosystem material and its interactions. Ecosystem material aids students in grasping the connections between living organisms and their surroundings, which encompasses the interplay between biotic and abiotic elements (Ramadhan et al., 2022). This comprehension is vital as ecosystem subjects also address global environmental challenges, including climate change, pollution, and the decline of biodiversity. Furthermore, Rizqi in his thesis entitled *"Persepsi Pserta Didik Tentang Sustainable Development Goals (SDGs) pada Konsep Lingkungan di SMA Adiwiyata dan Non Adiwiyata Kota Tangerang Selatan"* state that the study of ecosystem material is intrinsically linked to initiatives aimed at achieving the Sustainable Development Goals (SDGs), particularly goal 13 (Climate Action), goal 14 (Life Below Water), and goal 15 (Life on Land), which highlight the significance of mitigating climate change and conserving both terrestrial and marine ecosystems. Pursita et al., in their books entitled *"Critical Thinking and Ecoliteracy: Kecakapan Abad 21 untuk Menunjang Sustainable Development Goals"* state that the SDGs serve as a framework for sustainable development, both on a national and global scale, including in Indonesia. Teacher motivation and strategies are critical in improving the effectiveness of environmental education (Hadiapurwa et al., 2024). Through the exploration of ecosystem material, students are anticipated to develop an appreciation for and contribute to environmental conservation efforts, thereby becoming integral to the solution in realizing the SDGs in the future (Marpaung et al., 2023).

In addition to acquiring knowledge about ecosystem materials, contemporary biology education places significant emphasis on the necessity of 21st-century skills (Astutik & Hariyati, 2021). In this globalized era, students are expected not only to grasp scientific concepts but also to cultivate critical thinking, creativity, collaboration, and communication abilities (Khaira et al., 2023; Mardhiyah et al., 2021; Redhana, 2019). These competencies serve as a crucial foundation for students to confront and adapt to the challenges presented by the workforce and intricate global issues (Jaya et al., 2023). Besides, graduates should not only comprehend the theory behind 21st-century skills but also possess the capability to implement them. Such proficiency enables graduates to devise solutions to various challenges within their immediate environment (Karaca-Atik et al., 2024).

Nevertheless, evidence in the domain indicates that numerous educators encounter difficulties in delivering biology content that effectively fosters 21st-century skills among students (Black, 2020). The majority of instructional methods remain traditional, a finding corroborated by observational data from a school in Medan, which employs a teacher-centered strategy that fails to promote active student participation (Muliarta, 2018). Consequently, students from a school in Kudus city reported that only 35% of them had a comprehensive understanding of the ecosystem concept. At the same time, the remainder expressed challenges in connecting this concept to real-world environmental issues (Triana, 2023). Furthermore, their capacity for critical thinking and problem-solving—key indicators of 21st-century skills—was assessed as low, with an average score of only 2.8 out of 5. Additionally, the scarcity of media or modules pertinent to 21st-century skills-oriented learning further exacerbates these challenges.

An analysis of the biology textbooks utilized in the school reveals multiple deficiencies, including learning objectives that fail to promote 21st-century skills, a lack of variety in learning activities, and an inadequate presentation of material. For instance, the interactions among living organisms are limited to certain types, such as symbiosis and predation, while neglecting other important concepts like neutralism and antibiosis. Furthermore, certain visual aids, such as barcodes, are not readily accessible. Additionally, interviews conducted with teachers further confirm that students exhibit lower motivation levels due to the monotonous and less practical nature of the learning experience. Educators play a crucial role in crafting

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learning experiences centered on 21st-century skills (Adeoye et al., 2024). This includes the selection and development of instructional materials that facilitate a transition from a teacher-centered approach to a student-centered one. The incorporation of innovative and contextual teaching resources is vital for fostering an educational environment that adapts to contemporary needs. Consequently, the creation of learning modules that adhere to the principles of 21st-century skills represents a pertinent strategy for enhancing the quality of biology education.

It is essential to create a biology learning module that not only covers the topic of ecosystems but also actively engages students in activities that cultivate 21st-century skills (Rini et al., 2023). This module is specifically crafted with an interactive and applicable methodology, enabling students to grasp the concept of ecosystems while enhancing their critical thinking, collaboration, and creativity (Sholeh et al., 2023). Furthermore, the modules possess certain characteristics, which include: 1) Self-instructional; 2) Self-contained; 3) Standalone; 4) Adaptive; 5) User-friendly (Hakim et al., 2024; Wulansari et al., 2018). This aligns with the module's numerous advantages over traditional teaching materials, such as: 1) increased interactivity through activities that engage students; 2) inclusion of captivating illustrations to aid comprehension; 3) presentation of content with a more appealing visual format; and 4) a clearer and more organized delivery of information. Koroleva et al in their book entitled *"Genesis and Predictive Ability of Ecosystem Approach in Education"* state that students can enhance their 21st-century skills while deepening their understanding of ecosystem concepts. Furthermore, this module may address the shortcomings of traditional methods that are less effective in fostering the holistic development of students' skills (Okpatriona & Abdullah, 2024).

A learning module focused on 21st-century skills related to ecosystems is urgently required to address the challenges posed by contemporary education, which necessitates that students not only grasp theoretical concepts but also apply their knowledge in practical situations (Kimianti & Prasetyo, 2019; Lestari & Iryanti, 2024). Ecosystem materials are intrinsically linked to pressing global issues such as climate change and environmental conservation, necessitating a comprehensive understanding and practical skills (Kono et al., 2016). By utilizing appropriate modules, students are anticipated to be more adequately equipped to confront various real-world challenges and possess the capability to make sustainable decisions concerning environmental matters (Anggo et al., 2023; Dinihari et al., 2024). This urgency is amplified by the necessity for education to cultivate a generation that is environmentally conscious and capable of making positive contributions to the ecosystem (Warsah & Warsah, 2023). Research indicates that implementing 21st-century skills-based modules can enhance students' motivation to learn and their ability to connect theoretical knowledge with practical application, which is crucial for addressing real-world challenges (Dilekçi & Karatay, 2023).

Previous biology learning modules have been developed; however, many of these do not fully incorporate 21st-century skills into the ecosystem content (Aripin et al., 2020). Furthermore, students' cognitive understanding is often assessed without considering the modules' effects on the enhancement of non-cognitive skills, such as collaboration and communication (Sultanova, 2025; Ule et al., 2021). In the context of Indonesia, studies focusing on the creation of biology modules that integrate 21st-century skills are scarce, particularly those concerning ecosystem materials. This highlights a significant research gap that could be addressed through the formulation of a more comprehensive module centered on 21st-century skills (Irwan et al., 2019).

Consequently, the objective of this study is to create a biology learning module based on 21st-century skills that focuses on ecosystems and their interactions, specifically tailored for grade X high school students. It is anticipated that this module will enhance students' comprehension of ecosystem concepts in depth while also fostering critical, creative, collaborative, and communicative thinking abilities. Through this module, students are expected to engage more actively in the learning process and be better prepared to tackle real-world challenges.

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LITERATURE REVIEW

21st-Century Skills

The competencies required in the 21st century represent essential skills that learners must develop to navigate the complexities and competitiveness of contemporary society. The Partnership for 21st Century Learning identifies these core competencies—critical thinking, creativity, collaboration, and communication—as the 4Cs (Herlinawati et al., 2024; Komara & Hadiapurwa, 2024). The importance is not only in professional settings but also within scientific education, where problem-solving is a key focus (Redhana, 2019). Both creative and critical thinking involve the ability to analyze, adapt, make logical decisions, and generate original ideas (Facione, 2011; Guilford, 1967), In educational contexts, embedding 21st-century skills into the learning framework is essential to prepare students for the demands of technology, information, and global challenges. As a branch of science, biology education should encourage students to explore and apply concepts through real-world contexts that require higher-order thinking. Therefore, integrating 21st-century skills into the curriculum is crucial for producing graduates equipped to face modern societal challenges. This integration necessitates the use of contextual, participatory, and problem-based learning approaches by educators (González-pérez & Ramírez-montoya, 2022).

Learning Module

A learning module represents a specific category of educational material that is meticulously crafted for either independent use or guided instruction. This module serves as a comprehensive learning framework, encompassing objectives, content, learning activities, assessments, and opportunities for reflection. An effective module should be self-instructional, self-sufficient, adaptable, and user-friendly (Wulansari et al., 2018). In the realm of 21st-century education, modules should promote the cultivation of higher-order thinking and collaborative skills. Interactive modules are considered more effective in enhancing students' motivation to learn and their understanding of complex concepts. Modules focused on 21st-century skills can significantly boost students' active participation in the educational process (Sholeh et al., 2023). Consequently, the development of modules should not focus solely on content delivery, but also on learning strategies that foster exploration, dialogue, and problem-solving. Modules that incorporate a scientific approach, digitalization, and 4C skills are believed to facilitate meaningful and contextual learning experiences (Kurniasih et al., 2024).

Materials of Ecosystems in Relation to 21st Century Skills

Ecosystem material involves understanding the dynamic interactions between biotic and abiotic components, as well as the processes that maintain environmental balance. This topic is highly relevant to the development of 21st-century skills, as it bridges scientific knowledge with pressing global challenges such as climate change and biodiversity loss. Ecosystems represent a core concept in biology education, fostering students' critical thinking, real-world problem analysis, and the ability to develop sustainable solutions (Gulo, 2022). Within a learning framework that emphasizes 21st-century competencies, ecosystem content can be delivered through collaborative projects, group discussions, and localized case studies that promote reflection and effective communication. Ecosystem learning should steer students toward context-based problem-solving (Jayanti et al., 2024). Additionally, the integration of creative thinking encourages students to innovate in support of environmental sustainability. An ecosystem module designed with these competencies in mind allows learners to actively assess, elaborate, and construct knowledge. Thus, ecosystem material serves as a powerful medium for cultivating environmental

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awareness, logical reasoning, and collaborative skills within the broader goals of sustainable education (Palacios-Agundez et al., 2022).

METHODS

The approach employed in this study is the research and development method utilizing the 4D model. Based on Thiagarajan et al. in their book entitled *"Instructional Development for Training Teachers of Exceptional Children"* state that this model encompasses four stages, which are: 1) Define; 2) Design; 3) Develop; and 4) Disseminate. The progression of this development is illustrated in **Figure 1**.

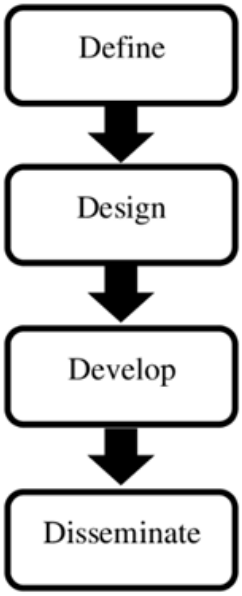

Figure 1. 4-D Model Design
Source: Thiagarajan et al., 1974

The participants in this research were students from class X at Madrasah Aliyah Laboratorium (MAL) Universitas Islam Negeri Sumatera Utara (UINSU). The tools employed in this investigation included interview guidelines for educators and questionnaires for students, which facilitated the gathering of data regarding the teaching materials utilized and the learning outcomes of the students. The validation document comprises a validation sheet for teaching material experts and another for material experts, which are employed to gather information concerning the evaluation of learning media from the validators. Additionally, the effectiveness assessment, represented by the student response questionnaire, was utilized to collect feedback from students regarding their comprehension of the material and the appeal of the learning media. The assessment consists of five essay questions focused on critical thinking, as outlined as well as the questions aimed at evaluating creative thinking skills which are to be completed individually (Facione, 2011; Guilford, 1967). The measurement scale for each indicator on both the validation sheet and the student responses is assessed using a Likert scale ranging from 1 to 4. This teaching material for the 21st-century skills module was created through a four-stage process.

Define Phase

During the defining phase, several critical analyses were performed to ensure that the developed module aligns with learning requirements. These analyses include front-end analysis, student analysis, concept analysis, task analysis, and specifying instructional objective. The purpose of front-end analysis is to identify the primary issues that underpin the module's development. Student analysis is conducted to gain

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insights into the characteristics of learners, encompassing their needs and their comprehension level of the material. Concept analysis assists in delineating the scope of the content to be taught, while task analysis identifies pertinent activities that facilitate learning. Specifying instructional objective is aimed at confirming that the module aids in achieving the desired competencies.

Design Phase

During the design phase, activities such as storyboard creation, material preparation, the development of assessment tools, and the formulation of learning strategies are undertaken. This phase also encompasses the design of preliminary prototypes, the selection of media and formats that align with student characteristics, and the preparation of criterion-referenced tests to facilitate the development of systematic and applicable educational content.

Develop Phase

The develop phase was carried out to transform the draft into a preliminary product and evaluate the validity, practicality, and effectiveness of the module. This phase encompasses expert appraisal to gather instructional and technical insights, along with restricted trials involving students to collect formative feedback. In light of these findings, the module was amended to enhance its suitability, quality, and optimal usability.

Disseminate Phase

The dissemination phase represents the concluding stage, which seeks to distribute the product to a broader audience in order to evaluate its effectiveness in educational contexts. Prior to dissemination, a summative evaluation is performed to confirm the material's success under actual conditions. Subsequently, the revised and validated materials are meticulously packaged and readied for distribution, facilitating their widespread adoption by both educators and learners.

The information for this research was gathered through both qualitative and quantitative methods. Qualitative data were sourced from interviews conducted with educators, along with feedback and recommendations from validators. In contrast, quantitative data encompassed assessment scores provided by validators, questionnaires filled out by teachers and students, as well as scores reflecting students' critical thinking and collaboration abilities. All collected data were subjected to descriptive analysis and processing, utilizing both qualitative and quantitative approaches. The validity of the learning module focused on 21st-century skills was evaluated based on the assessment scores from expert validators. Conversely, the module's practicality was determined through the evaluation results from both teachers and students. The quantitative data collected were subsequently analyzed using criteria calculation. Additionally, the findings from the validity and practicality analysis of the module were interpreted in accordance with the criteria outlined in **Table 1**.

Table 1. Validation Assessment Result Criteria

Percentage (%)	Criteria
80,00-100,0	Highly Valid/ Highly Practical
60,00-79,99	Valid/Practical
50,00-59,99	Quite Valid/Quite Practical
00,00-49,99	Invalid/Not Practical

Source: Riduwan and Akdon in their book "Rumus dan Data dalam Analisis Statistika" 2010

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The efficacy of the skills-based learning module for the 21st-century was determined through the N-Gain calculation. The analysis of the N-Gain calculation outcomes is based on the information presented in **Table 2**.

Tabel 2. N-Gain Criteria

N-Gain	Criteria
g > 0,7	High
0,3 < g < 0,7	Medium
g < 0,3	Low

Source: Nasution and Rasyidah, 2022

RESULTS AND DISCUSSION

This research on development resulted in a learning module focused on 21st-century skills related to ecosystem materials. The learning module, designed to foster essential 21st-century skills such as critical thinking, creative thinking, communication, and collaboration, was constructed through a four-stage process following the 4D model. The subsequent sections outline the findings from each stage of the learning module's development in this study.

Define Phase

The Define stage encompasses five primary steps: Front-End Analysis, Learner Analysis, Concept Analysis, Task Analysis, and Specifying instructional objective. This stage aims to identify and ascertain the needs within the learning process.

1. Front-End Analysis
   The findings from observations and interviews conducted at Madrasah Aliyah Laboratorium indicate that students' proficiency in 21st century skills remains inadequate. Instruction predominantly relies on lectures and textbooks, and class sizes are relatively large. The educator noted that students exhibit low motivation to learn, as the material has not been delivered in an engaging and practical way.
2. Learner Analysis
   The findings from the questionnaire indicate that the learning media currently employed are perceived as unengaging and repetitive. Students articulated a desire for a module that is more interactive and aligns better with their individual learning preferences.
3. Concept Analysis
   Ecosystem material was selected due to its significance in fostering conceptual understanding and the application of 21st-century skills, including critical thinking, creativity, collaboration, and communication. Concept analysis pertains to the learning outcomes outlined in the Kurikulum Merdeka, concentrating on the development of relevant and applicable learning objectives.
4. Task Analysis
   Task analysis indicates that students require educational experiences that prioritize the application of ecosystem concepts and the mastery of 21st-century skills, especially critical and creative thinking, to address contextual challenges and generate innovative solutions.
5. Specifying instructional objective
   Learning outcomes are established in accordance with Permendikbudristek Nomor 32 Tahun 2024 tentang Kurikulum Merdeka. The learning objectives to be accomplished are: 1) Through observations

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of their immediate environment, learners should be able to accurately identify components of ecosystems. 2) Through observations of their immediate environment, learners should be able to appropriately differentiate between various types of ecosystems based on their characteristics. 3) Through observation of their immediate environment, students should be able to accurately design different types of interactions within ecosystems. 4) By examining images of food chain diagrams or energy pyramids, learners should be able to correctly analyze the flow of energy within ecosystems. 5) By examining images of biogeochemical cycles, learners should be able to accurately describe these cycles.

The Define phase recognized the necessity for a contextual learning module aimed at enhancing 21st-century skills. The front-end analysis indicated that the learning process was predominantly teacher-centered, lacked engagement, and failed to foster students' motivation—similar to the previous observations (Muliarta, 2018). The learner analysis revealed that students were seeking more interactive media, which resonates with the findings of Adiatma and Thana who underscored the significance of engaging materials (Adiatma & Thana, 2022). The concept analysis validated the selection of ecosystem content due to its relevance to critical, creative, communicative, and collaborative skills (Adlini et al., 2024). Ecosystem topics effectively nurture critical thinking by engaging learners in authentic, context-based learning experiences, a need highlighted by the task analysis and the importance of contextual eco-based education (Dinihari et al., 2024; Kono et al.,2016). Subsequently, instructional objectives were formulated in accordance with Permendikbudristek Nomor 32 Tahun 2024 tentang Kurikulum Merdeka, ensuring compliance with national standards. In summary, this phase established a robust foundation for module design by integrating student needs, curriculum requirements, and research findings.

Design Phase

Informed by the findings from the analysis conducted during the Define phase, the researchers developed a biology learning module specifically aimed at enhancing 21st-century competencies. The module was designed to support students in acquiring a comprehensive understanding of ecosystem concepts while simultaneously fostering critical thinking, creative thinking, collaboration, and communication skills (4C). Structurally, the module comprises essential components such as a cover, preface, table of contents, list of figures, usage instructions, introduction, concept map, diagnostic assessment, two core learning activities, summative assessment, bibliography, answer key, glossary, and author biography. During the Design phase, careful attention was given not only to the organization of content but also to visual and aesthetic elements—such as color gradients, image layout, and the engaging presentation of information—utilizing the Canva application as the primary design tool. To ensure its quality, the researchers constructed several validation instruments, including expert validation sheets to assess content and media feasibility, student and teacher questionnaires to evaluate practicality, and test blueprints for pre-tests and post-tests to examine learning effectiveness.

The integration of 21st-century skills was achieved through well-designed learning activities that encouraged students to analyze real-world ecological problems, evaluate potential solutions, and generate creative ideas through collaborative discussions and problem-solving exercises, as detailed in **Table 3**. The outcomes from the Define phase underscored the urgent need for student-centered modules aligned with 21st-century educational demands in biology. This development aligns with previous research which emphasized the importance of embedding 4C skills in science education (Adlini et al., 2024; Aripin et al., 2020). Moreover, the reliance on lecture-based teaching observed during preliminary fieldwork echoes the instructional shortcomings (Muliarta, 2018). To address these limitations, the module was designed with visually engaging and structurally coherent content (Adiatma & Thana, 2022). The emphasis on ecological reasoning and contextual learning further supports the relevance of this module and reinforcing its value within the broader framework of 21st-century biology instruction (Dinihari et al., 2024).

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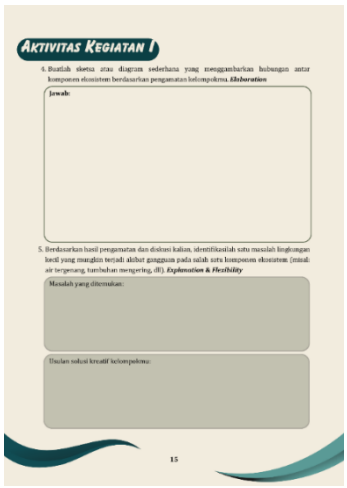
Tabel 3. Integration of 21st-century skills in learning module

Module application illustration	Learning activities	Integration of 21st-century skills
	Students examine the interactions among ecosystem components using QR codes and assess the issues arising from these interactions.	Students evaluate the relationships between ecosystem components by connecting potential future consequences to ecosystem degradation. This process is integrated with critical thinking skills.
	Students investigate their immediate environment, noting the interactions among its components, and devise solutions to ecosystem challenges based on group observations.	Students innovate by assessing the actual conditions of the ecosystem they study, subsequently developing original and practical solutions, which they illustrate or present as posters. This activity fosters creative thinking and collaboration skills.
	Students analyze the food chain and articulate the causes and effects that manifest within it.	Students convey their group's perspective regarding the food chain discussed in the module and present their findings to the class. This exercise enhances critical thinking and communication skills.

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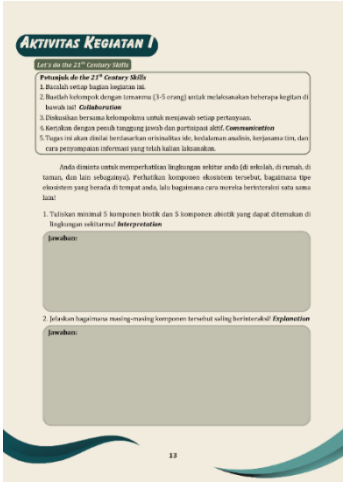
Module application illustration	Learning activities	Integration of 21st-century skills
	Students explore the ecosystem in their surroundings by forming groups to analyze the ecosystem's challenges.	Students assess real-world conditions, interpret the interconnections among ecosystem components, and formulate coherent explanations. This task is integrated with critical thinking and collaborative skills.

Source: Research 2025

Develop Phase

In this phase, following the design stage of the 21st-century skills-based biology learning module, the development of the module can commence. This development encompasses the design of prototypes and subsequent testing of the product for its validity and practicality. This stage is essential in the development process, as the outcomes serve as the foundation for assessing the module's feasibility and effectiveness prior to broader implementation. Activities during this phase involve validation by experts, including media specialists, subject matter experts, and specialists in 21st-century skills, along with trials of the module conducted with students to evaluate its impact on enhancing students' critical and creative thinking abilities. The data obtained from the validation process were utilized to evaluate the module's completeness, content quality, language, presentation, as well as its graphic and technical features. Concurrently, data from student trials were analyzed using pre-test and post-test methodologies to gauge the enhancement of critical and creative thinking skills. The content is structured according to a specified outline to facilitate a comprehensive understanding for students, supplemented by examples of learning activities that are pertinent to the Kurikulum Merdeka and 21st-century skills.

1. Expert Appraisal

The validity of this educational module was evaluated by three expert validators, each concentrating on the elements of learning media, ecosystem materials, and 21st-century skills. The evaluation was conducted using a validation instrument in the form of a questionnaire, employing a Likert scale ranging from 1 to 4, which was tailored to the indicators associated with each aspect. The validation outcomes from media experts revealed that the module achieved a cumulative score of 109 out of a possible 117, resulting in a validity percentage of 93.16%. This signifies that the module is categorized as very valid concerning learning media. Additionally, the validation from ecosystem material experts yielded a score of 86 out of a total of 92, corresponding to a validity percentage of 93.47%, which is also classified as very valid. The validation results from experts in 21st-century skills indicated a total score of 60 out of a maximum of 64, equating to a percentage of 93.75%, thereby affirming that the module is deemed very valid in facilitating the development of 21st-century skills. In summary, the findings from this validation process suggest that the developed module has fulfilled the criteria for content eligibility, presentation, and alignment with the characteristics of 21st-century learning in **Table 4**.

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Table 4. Outcomes of validation conducted by validators

Validator	Aspects	Score obtained	Maximal score	Percentage	Category
Media Expert	Completeness	13	13	100,0%	Highly valid
	Quality	63	68	92,64%	
	Graphics	33	36	91,66%	
	Total	**109**	**117**	**93,16%**	
Materials Expert	Content	24	28	85,71%	Highly valid
	Language	32	32	100,0%	
	Presentation	30	32	93,75%	
	Total	**86**	**92**	**93,47%**	
21st Century Skills Expert	Critical thinking	15	16	93,75%	Highly valid
	Creative thinking	16	16	100,0%	
	Communication	15	16	93,75%	
	Collaboration	14	16	87,50%	
	Total	**60**	**64**	**93,75%**	

Source: Research 2025

2. Developmental Testing

Following the necessary revisions, the book's practicality was assessed through feedback obtained from both students and educators. The subsequent phase involved executing a small-scale pilot test by distributing questionnaires that included responses from teachers and students. The evaluation outcomes revealed a practicality score of 92.06% from students and 100% from teachers, with both evaluations categorized as very practical in **Table 5**. This feedback was instrumental in enhancing the quality of the product, ensuring that the module was informative, engaging, and tailored to the needs of its users. The high practicality of this module can be attributed to several factors. The primary factor is that this learning module is exceptionally user-friendly for both educators and students during the learning process. This aligns with the previous research which indicates that the practicality of teaching materials or learning media is contingent upon the ease with which teachers and students can employ them in the educational process (Adiatma & Thana, 2022).

Table 5. The Results of Practicality by Student and Teacher

Respondent	Percentage	Category
Student	92,06%	Highly Practical
Teacher	100,0%	Highly Practical

Source: Research 2025

The results from the effectiveness tests further substantiate the enhancement of critical and creative thinking abilities, with students' average scores increasing from 35.5 to 87.33 following the utilization of the module in **Table 6**. This finding corroborates the assertion that this learning module, which is centered on 21st-century skills, fortifies students' critical and creative thinking capabilities (Dilekçi & Karatay, 2023). Furthermore, there is another finding at project-based modules, which yielded an N-Gain of 0.51 (Marten et al., 2019). In a similar vein, another research reported that e-modules based on the Inquiry model integrated with the SETS (Science, Environment, Technology, and Society) approach effectively improved

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students' 21st-century skills, with N-Gain scores of 0.76 for critical thinking, 0.77 for creative thinking, and 0.71 for collaboration (Wati & Syafriani, 2023). These results highlight the significance of inquiry-based digital resources in enhancing key competencies. Likewise, physics modules integrated with Problem-Based Learning were effective in enhancing students' critical and creative thinking, as evidenced by notable improvements in student performance (Selviana et al., 2022). Their findings support the conclusion that PBL-based modules serve as powerful tools in promoting essential 21st-century skills.

Tabel 6. Effectiveness Test Results as Assessed by Students

Pre-test	Post-test	N-Gain	Percentage	Category
35.5	87.33	0.812823337	81.28%	High

Source: Research 2025

Disseminate Phase

The dissemination stage represents the concluding phase in the 4D development model, which is designed to share the developed learning module with a broader audience. Following revisions to the teaching material components informed by expert feedback and preliminary trials, the biology learning module focused on ecosystems, which emphasizes 21st-century skills, was subjected to limited testing among grade X students at Madrasah Aliyah Laboratorium UIN North Sumatra. This testing aimed to assess its effectiveness in fostering critical and creative thinking skills. The evaluation process involved pretest and posttest analyses grounded in Facione critical thinking indicators, which encompass interpretation, analysis, inference, evaluation, explanation, and self-regulation, alongside Guilford creative thinking indicators, specifically fluency, flexibility, originality, and elaboration (Facione, 2011; Guilford, 1967). The findings indicated a notable enhancement across all dimensions, with an average N-Gain value of 0.81, categorizing the module's effectiveness as high. In addition to the limited testing, the researchers produced a small number of modules and distributed them to partner schools as part of the initial dissemination effort. This phase is intended not only to evaluate the module's effectiveness in a practical setting but also to serve as a preliminary step in sharing the module with other educators and students, thereby facilitating its broader application in 21st-century skills-based biology education.

In assessing the indicators of interpretation and fluency, students demonstrated the ability to accurately interpret information and generate a wide range of ideas through the case study presented in the module. The use of LKPD or interactive modules based on case studies enhances students' cognitive skills in understanding and interpreting information (Adawiyah et al., 2022; Rosyiddin et al., 2023). Improvements were also observed in the indicators of analysis and flexibility, as students' observations of food chains within ecosystems encouraged them to analyze issues, construct arguments, and evaluate solutions logically while producing diverse ideas. PBL-based ecosystem observations effectively foster students' analytical thinking and flexibility in understanding ecosystem structures. Inference skills also showed notable progress, with students drawing conclusions from evidence gathered during collaborative discussions and guided inquiry significantly improves students' ability to make logical inferences (Kono et al., 2016; Ridzal et al., 2023).

Regarding evaluation and originality, students demonstrated the capacity to assess strategies for addressing environmental issues and to generate innovative ideas about ecosystem interactions. This supports the findings of Putri and Alberida who emphasized that creative thinking development enables students to produce original, contextually relevant ideas (Putri & Alberida, 2022). Additionally, students' ability to articulate explanations improved, as evidenced by their systematic communication of scientific reasoning and arguments during group discussions (Adawiyah et al., 2022). Lastly, indicators of self-regulation and elaboration also advanced, with students becoming more adept at setting learning goals,

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organizing their thoughts, and expanding their ideas in greater depth. This is in line with the learning grounded in 21st-century skills fosters autonomy and the deep development of ideas (Jayanti et al., 2024).

In summary, the biology learning module focused on 21st-century skills concerning ecosystems has been designed for tenth-grade students. Its purpose is to enhance comprehension of ecosystem concepts while simultaneously cultivating critical and creative thinking abilities in alignment with the demands of the 21st-century. This approach supports the conclusions drawn by the previous research, which highlight the significance of 21st-century skills-based learning models (Adlini et al., 2024; Jayanti et al., 2024). Such models equip students to better confront future challenges and enhance their educational achievements. Furthermore, the 21st-century skills are crucial for students as they engage with real-world problems, allowing them to debate and investigate concepts or draw conclusions during the learning process (Sari & Trisnawati, 2019; Sinurat et al., 2023).

Although the effectiveness test demonstrated significant improvements in students' critical and creative thinking skills, the assessment of 21st-century competencies in this study did not sufficiently address the dimensions of collaboration and communication. The module still relies heavily on the use of digital devices for individual tasks, resulting in limited direct interaction among students during group work and oral discussions—an aspect that was not fully captured by the evaluation instruments. To address this gap, the implementation of the module in classroom settings should be complemented by teacher-led strategies, such as forming discussion groups and facilitating collaborative presentations on ecosystem analysis. These approaches can enhance students' communication and teamwork abilities. Moreover, educators must provide active support to ensure that student engagement goes beyond online or independent activities, encouraging more direct, interpersonal exchanges. Thus, the module's limitations in covering all aspects of 21st-century skills can be mitigated through thoughtful pedagogical innovations integrated throughout the teaching and learning process.

CONCLUSION

This research successfully developed a biology learning module centered on 21st-century skills, specifically designed to improve students' understanding of ecosystems while fostering essential skills such as critical thinking, creativity, collaboration, and communication. The study demonstrates that integrating these skills into biology education is not only feasible but necessary to prepare students for future challenges, particularly those related to environmental issues like climate change and biodiversity loss. The module's design and subsequent validation processes indicated that it is highly effective in enhancing students' critical and creative thinking abilities, with significant improvements observed in pre-test and post-test scores.

The findings of this study contribute to the literature by providing a practical solution for the integration of 21st-century skills in the teaching of ecosystem materials, filling a gap in current educational practices. From a theoretical standpoint, it reinforces the idea that interactive, student-centered learning approaches are essential for developing higher-order thinking skills. Practically, this research offers educators a robust tool for engaging students more deeply in the subject matter, thus preparing them to address real-world problems. Policymakers can use these findings to support the adoption of curriculum reforms that emphasize skills-based learning in science education.

Future research could explore the module's application in diverse educational settings, including schools with varying technological access, to assess its adaptability and effectiveness across different contexts. Further studies could also examine the long-term impact of this approach on students' ability to apply 21st-century skills in other subjects or in real-life scenarios. The implementation of collaborative learning strategies alongside the module could also be investigated to better enhance students' communication and teamwork skills.

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