

Development of citizen science-based e-modules to improve student learning outcomes in biodiversity materials

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ABSTRACT

Learning biology on biodiversity is often perceived as difficult by students due to complex scientific terms and the large volume of information to memorize, which can lower motivation and affect learning outcomes. To address this issue, this study developed citizen science-based e-modules aimed at improving student understanding and learning outcomes. These e-modules integrate technology and engage students in scientific research activities. The research used a research and development method with the 4D model: define, design, develop, and disseminate. Validation from material, media, and language experts showed the e-modules were highly feasible, scoring 1.00. To test effectiveness, post-test results from experimental and control groups were compared using the Mann-Whitney U test, revealing a significant difference in learning outcomes favoring the experimental group using the e-modules. The results demonstrate that the e-modules are effective for teaching biodiversity in high school. Additionally, student feedback was positive, with 62% strongly agreeing that the e-modules supported the learning process. This study concludes that citizen science-based e-modules are an effective, engaging, and innovative medium for improving student learning outcomes in biology, particularly in biodiversity topics, and are recommended for use in high school classrooms.

Keywords: e-module, citizen science, learning outcomes, biodiversity

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INTRODUCTION

The media plays an important role in education as a tool for teachers to deliver material. Without media, students can have difficulty understanding lessons. Therefore, teachers must be creative in utilizing technology according to the needs of students (Fadilah et al., 2023). E-modules are non-print digital learning resources that are systematically designed and used for self-study purposes, to help students learn to solve problems in their own way. The e-module can be used on a mobile phone, computer, or laptop. These modules are distributed to students online through platforms such as Google Classroom or apps such as WhatsApp and can also be shared offline with storage media if needed. The use of electronic modules (e-modules) harnesses the power of technology to create a powerful and effective learning experience due to its unique and engaging appearance (Gufran & Mataya, 2020).

Learning biology is often considered difficult and tedious because many Latin terms are difficult to memorize.

The use of images and videos helps visualize complex concepts. Therefore, electronic modules are important because they present diverse materials such as text, images, and videos that support learning and adapt to the needs of students (Puspitasari et al., 2020). Biodiversity material is considered difficult by students because the discussion is too general, complex, and not associated with the local context. Dona and Selaras (2024) show that 66% of students find it difficult to understand this material due to the abundance of information and scientific terms. Sarip et al. (2022) also revealed other obstacles such as complex language use, limited learning resources, and a lack of easy-to-understand textbooks.

Citizen science in general is the participation of community groups or citizens in research that goes beyond the boundaries of research institutions. Citizen science contributes greatly to scientific research through citizen participation in data collection, analysis, and interpretation (Tolbert et al., 2024). Citizen science is a process by which students can participate in scientific research. Students

Table 1. 4D development model

No	Stage	Explanation	Instruments
1	Define	Analyze problems and needs before compiling modules.	1. Teacher interviews 2. Student needs analysis questionnaire
2	Design	Designing learning concepts, module frameworks, and product validation instruments.	Storyboard
3	Develop	This includes the creation of teaching materials and e-module products that have been created, which are then validated by media experts, material experts and linguists to assess the feasibility of the e-modules that have been developed.	Product validation questionnaire
4	Disseminate	Socializing e-modules through learning in schools and evaluating the effectiveness of modules in improving student learning outcomes.	1. Formative questions 2. Student response questionnaire

participate in research projects led by professional researchers to learn about nature. The goal of learning biodiversity in high school is to understand the concepts of biology, ecosystem structure, threats, and conservation. Students also develop observational and analytical skills and apply knowledge to support environmental protection efforts (Muaziyah et al., 2023).

Citizen science-based electronic modules utilize technology to support flexible and engaging learning, especially for students with visual and kinesthetic learning styles. Interactive electronic modules correspond to current technological developments and educational demands (Rambe & Ristiono, 2022). Understanding students' learning styles is important for improving interaction and learning effectiveness. Students who have a visual learning style can more easily understand material through graphics and animations, while students with an auditory learning style can benefit from voice explanations (Minasari & Susanti, 2023; Puri & Wiyatmo, 2024; Rahmi et al., 2025).

In the context of citizen science, students get hands-on feedback on their contributions to research, which encourages reflection and deepens understanding of biological matter. Several studies have shown that citizen science connects students with authentic scientific research, improves understanding through data collection and analysis, and engages communities in environmental issues. The project also opens up opportunities for teachers to collaborate with researchers to expand the horizons of teaching (Aristeidou et al., 2023; Berndt & Nitz, 2023; Van Haeften et al., 2021).

The citizen science approach has proven to be effective in improving people's scientific literacy and their involvement in environmental issues. Some studies say citizen science projects balance scientific rigor, policy, and social benefits. In addition to collecting data, the project improves participants' knowledge and skills, opening up opportunities for students to actively participate in research, conservation, and research skill development (Bedessem et al., 2022; Fajri et al., 2021; Golumbic, 2024).

Learning at one of the high schools in Cirebon still focuses on printed books without e-modules for biodiversity. It is necessary to innovate interactive learning materials, integrating the environment as a learning resource. Most of the students in one of the high schools in Cirebon are not familiar with citizen science, because the

results of preliminary observations and research as shown by Gusti et al. (2024) that 85.32% of students do not know this term. Formal education, non-formal activities, and access to technology play an important role in their understanding. Therefore, this research is needed to introduce citizen science more widely.

Based on the problems that have been identified, this research was conducted to develop citizen science-based e-modules as an innovative solution in biodiversity learning. This development is designed to support 21st century learning skills, such as critical thinking skills, collaboration, science literacy, and environmental awareness. This study not only examines the feasibility of the developed product but also analyzes the influence of its use on improving learning outcomes and active participation of students in the learning process.

METHODOLOGY

Research Design

This type of research is research and development using a 4D model: define, design, develop, and disseminate. The stages of the research are in accordance with the 4D development model in [Table 1](#).

Sampling and Data Collection

Population is the entire subject of the research. In this study, the population is all students of class X of Al-Azhar 5 Islamic High School Cirebon. The sample is a part or representative of the population studied. The sample of this study is class X-3 which totals 32 people. The class is a sample in the implementation of citizen science-based e-modules on biodiversity materials that have been developed. Different student photos of the students are given in [Appendix A](#).

Analyzing Data

Data analysis was carried out using the Gregory formula to test the content validity based on the level of agreement between experts on the suitability of the instrument item with the measured indicator. Furthermore, the assessment of education practitioners was analyzed using the content validity ratio (CVR) and content validity index (CVI) methods to determine the feasibility level of the instrument. The data from the student response questionnaire was analyzed

using descriptive statistical analysis to determine the acceptance rate and feasibility of the product.

Hypothesis

Hypothesis tests were carried out to determine the difference in student learning outcomes between the experimental class and the control class. The hypothesis tested was H_0 : there was no difference in improving student learning outcomes, and H_1 : there was a difference in improving student learning outcomes. Because one of the groups did not meet the assumption of normality, the analysis used the Mann-Whitney U test with a significance level of 0.05. A value of $p < 0.05$ indicates that H_0 is rejected, while $p > 0.05$ indicates that H_0 is accepted.

RESULTS AND DISCUSSION

This research is titled "Development of citizen science-based e-modules to improve student learning outcomes in biodiversity materials." Citizen science in education not only teaches scientific concepts but also provides opportunities for students to engage directly in research. This concept encourages students to learn through experience, think critically, collaborate, and actively participate in life-relevant research. This research developed an e-module using a 4D model. At the define stage, an analysis of the curriculum, materials, and needs of teachers and students is carried out. The results of the analysis show that the school implements the Independent Curriculum, especially phase E which emphasizes understanding global issues and the active role of students, including in the topic of biodiversity. However, based on the results of the research, learning still relies on printed books and PowerPoint. Teachers experience limited time in creating digital media, while students are enthusiastic about biology and prefer interactive digital media. Therefore, citizen science-based e-modules are needed that not only convey theories but also develop research skills and provide real experience in collecting and analyzing scientific data.

The design stage is based on the results of define which shows the need for an attractive and easy-to-use e-module where the e-module must convey information while making users interested and actively engaged. Therefore, the design includes engaging visual elements, an easy-to-understand display, and features that support the understanding of the material for effective and enjoyable learning. This stage includes making a design (storyboard) and preparing research instruments.

The develop stage was carried out after the design stage is completed, which is to apply the design into a trial-ready e-module product. This stage includes the creation of an e-module and validation by three experts (media, materials, language) and education practitioners, namely high school biology teachers. The electronic module is created using the Canva app with A4 paper size. The cover consists of the first page containing the institution's logo, the title of the e-module, the material, the class, and the identity of the

author, and the last page containing a summary of the contents, a brief biography, and the author's contacts. The electronic modules are validated by experts and practitioners to assess feasibility. Material validation ensures content is in accordance with the curriculum, scientific accuracy, and relevance to learning objectives. The results of instrument validation were analyzed using the Gregory formula by comparing the results of the assessment from two subject matter experts. The assessment was carried out using the Likert scale, then the scores obtained were categorized into two groups, namely relevant and irrelevant. Furthermore, the level of validity is calculated based on the agreement of the two validators on each item of the instrument. The display of module e based on citizen science on biodiversity materials in **Figure 1**.

Based on the results of the validation of citizen science-based e-modules on biodiversity materials using the Gregory formula, a score of 1 was obtained and was included in the very feasible category. This module is suitable for use because it is in accordance with the learning objectives of stage E in the independent Curriculum, helping students understand the material in accordance with the curriculum competencies. The subject matter expert's assessment includes aspects of the e-module that are self-explanatory and self-contained, self-contained, adaptive, and user-friendly. E-modules are considered very feasible because they meet the characteristics of the modules described by the characteristics of the modules are self-instruction, which allows for self-paced learning. This is in accordance with the research conducted by Jusuf (2021) all the necessary materials are in the module. Stand-alone, the modules do not depend on other teaching materials. Adaptive, having the ability to adapt to the advancement of science and technology. User-friendly, every piece of information presented can help make it easier for users. Thus, in addition to meeting the criteria for e-modules structurally, e-modules are also superior in terms of functionality, this is also in accordance with the research conducted by Suri and Purwanto (2024) where in terms of function and usability, interactive e-modules can replace the role of teachers in several aspects of learning and are presented through electronic media so that they can be accessed anytime and anywhere by students.

Validation by media experts aims to assess the quality of e-module media from visual aspects, use of letters, navigation, and ease of use. Attractive designs can support comprehension, easy-to-read fonts improve convenience, clear navigation makes it easy for students to move between sections, and easy-to-access electronic modules on a variety of devices support an effective and enjoyable learning experience.

This e-module is suitable as a learning medium because it suits the needs of students, is easily accessible, interactive, and uses various types of media. According to them this e-module is interactive with navigation buttons that make it easy to access the material, complete with clear instructions for use. Attractive designs and informative



Figure 1. E-module display (the authors' own elaboration)

Table 2. Results of analysis of education practitioners

Item no	N	$\frac{N}{2}$	$N - \frac{N}{2}$	$CVR = \frac{N - \frac{N}{2}}{\frac{N}{2}}$	Minimum CVR value	Information
1	5	2.5	2.5	1	1	Very worthy
2	5	2.5	2.5	1	1	Very worthy
3	5	2.5	2.5	1	1	Very worthy
4	5	2.5	2.5	1	1	Very worthy
5	5	2.5	2.5	1	1	Very worthy
6	5	2.5	2.5	1	1	Very worthy
7	5	2.5	2.5	1	1	Very worthy
8	5	2.5	2.5	1	1	Very worthy
9	5	2.5	2.5	1	1	Very worthy
10	5	2.5	2.5	1	1	Very worthy

Note. $\sum CVR = 10$ & $CVI = \frac{10}{10} = 1$ (very worthy)

images and videos help students understand the material more easily. As explained by Lestari and Nugrahani (2021) the learning media, it is divided into three main types, namely graphic, audio, and real media. Graphic media presents facts, ideas, or ideas through text, numbers, symbols, or images to clarify concepts and make it easier for students to remember the material.

This linguist validation aims to test the feasibility in terms of language, namely communicative, straightforward, conformity with the correct Indonesian language rules and the use of terms and symbols in the e-module. Based on the results of the validation of citizen science-based e-modules on biodiversity materials using the Gregory formula, a value of 1 was obtained and included in the very feasible category. This e-module is feasible in terms of language because it uses good and correct Indonesian, with a writing format according to the rules. The sentences are clear, easy to understand, and neatly structured, making it easier for students to understand and follow the material comfortably. As expressed by language, it is also communicative which has a function as a way of

communicating in order to achieve a purpose that wants to be conveyed to others. According to e-modules, they are used as teaching materials that support independent learning because the language is communicative and interactive, making it easier for students to understand the material and assess the extent of their understanding (Hastuti et al., 2020; Purba et al., 2021).

Validation by education practitioners is carried out to assess the feasibility of learning materials, methods, and media to be in line with curriculum standards and the real needs of students in schools. Through this process, it is hoped that the e-modules developed can be used effectively in learning activities and in accordance with the characteristics of students in the field. The results of validation from educational practitioners can be seen in **Table 2**.

Based on **Table 2**, the results of the validation of education practitioners were obtained with a score of 1 and were included in the very feasible category. This e-module is said to be feasible from the perspective of education

Table 3. Normality test results

Classes	Quantity	Significance
Controls	32 students	0.174
Experiments	32 students	0.039

practitioners because it is designed to meet the needs and challenges faced by teachers in teaching. This module makes it easier for teachers to manage learning, because the material is arranged in a clear and orderly way, making it easy to use in the classroom. This is in accordance with the research conducted that e-modules can improve the learning process and are expected to be further developed to increase their attractiveness and effectiveness. According to a good module, it must have the feasibility of accurate and complete content, systematic presentation of learning, and communicative and easy-to-understand language. According to students, not only depends on the teacher, but also learns independently and is directed to complete tasks. This experience helps students discover new knowledge and solve problems, with a better understanding if the learning medium is right (Bashir et al., 2024; Dewi & Lestari, 2020; Rahma et al., 2023).

This e-module is suitable for use as a learning medium because it effectively conveys material and increases student involvement. Relevant interactive content facilitates understanding and supports cognitive development, both in the classroom and independently. Multimedia elements such as images and videos enrich the learning experience and encourage students to connect biodiversity materials with the surrounding environment through direct observation (Dahlia et al., 2024; Hanifah et al., 2023; Mansyur, 2020; Wahyuningsih et al., 2020)

The disseminate stage is the stage of disseminating products that have been developed and declared valid and suitable for use. In this study, dissemination activities were carried out on a limited basis through direct implementation in the classroom. The revised e-module based on the validator's input is then applied in the learning process to see the implementation and response of students. Thus, the disseminate stage aims to ensure that the developed product can be used effectively in real learning situations. Normality tests are carried out to find out whether the data from the research results are distributed normally or not. Based on the test results, it was obtained that the data was not normally distributed and did not meet the homogeneity assumption. Therefore, the data analysis was continued using a nonparametric hypothesis test, namely the Mann-Whitney U test. The results of the normality test are presented in **Table 3**.

The results of the normality test in **Table 3** show that the significance value in the experimental class is $p = 0.039$ (< 0.05), so that the data in the experimental class is declared not to be normally distributed. Meanwhile, the significance value in the control class was $p = 0.174$ (> 0.05), so that the data in the control class was declared to be normally distributed. Although one of the groups (the control class) showed a normal distribution, the analysis continued using

Table 4. Mann-Whitney U test: t-test results

Test	Significance	Remarks
Mann-Whitney U test	0.001	Significant differences

non-parametric tests for both groups because the assumption of normality was not met in all the groups being compared. Next, a homogeneity test was performed to find out whether the variance between the two data groups was homogeneous. The results of the homogeneity test showed that the significance value was $p = 0.111$ (> 0.05), so it can be concluded that both groups have homogeneous variance.

In determining the significance of the difference between the two classes, a hypothesis test was carried out using the Mann-Whitney U test at a significance level of 0.05. The use of this test was chosen because one of the groups did not meet the assumption of normality, even though the variance of the two groups was homogeneous. The Mann-Whitney U test is categorized as significant if significance 2 tailed < 0.05 . Results of the Mann-Whitney U test in **Table 4**.

The results of the Mann-Whitney U test showed a significance value (significance 2-tailed) of $p = 0.001$ (< 0.05). Thus, it can be concluded that there is a statistically significant difference in learning outcomes between classes that use citizen science-based e-modules and classes that do not use e-modules.

Based on the results of the tests that have been carried out, a significance value of 0.001 was obtained, which is smaller than 0.05. This shows that there is a significant difference between student learning outcomes in experimental classes that use citizen science-based e-modules and control classes that do not use e-modules. Thus, the use of civics-based e-modules has been proven to be effective in improving student learning outcomes. This is in accordance with research conducted by Makhmudin et al. (2024) the use of e-modules effectively in supporting the learning process, as it not only increases students' motivation to learn, but also contributes to improving learning outcomes.

E-modules facilitate the achievement of learning objectives through the presentation of materials that are systematic, interactive, and easily accessible. Meanwhile, according to Dakhi (2020) to the improvement of student learning outcomes, it can also be achieved through effective learning by using interesting and fun learning methods and models.

Improving student learning outcomes can be done by applying the Wiggins understanding aspect based on understanding by design (UbD). In line with the research conducted by UbD, UbD emphasizes in-depth understanding with a focus on meaningful and applicative outcomes. In the Gloria et al. (2019) citizen science e-module, UbD's application indicators encourage students to observe biodiversity firsthand, practicing observation, analysis, and environmental awareness skills for more relevant learning.

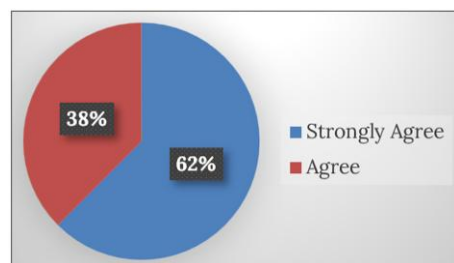


Figure 2. Percentage of student response questionnaire results (the authors' own elaboration)

Citizen science-based electronic modules not only improve learning outcomes but also provide hands-on experience in observing the environment through projects. Interactive media such as videos and infographics support a visual understanding of concepts. In accordance with the research conducted by Moha et al. (2024) and Mutia et al. (2025) project-based learning encourages active participation, problem-solving, and deep understanding. Meanwhile, according to Leksono et al. (2020), the mini-research project is effective in training students to analyze environmental conservation issues.

Student learning outcomes are not only determined by tests, but also influenced by other factors such as intelligence, motivation, and learning style. According to Irawati et al. (2021) learning, it plays an important role in improving student learning outcomes. Understanding learning styles helps teachers design more effective teaching strategies. Learning success is influenced by internal factors, such as intelligence, attitude, and motivation, as well as external factors, such as learning media and learning environment. Meanwhile, according to Astiti et al. (2021) and Hamzah et al. (2024) a conducive environment, supported by the right media and teaching aids, also supports the achievement of optimal learning outcomes.

The student response questionnaire was used to collect feedback related to the use of citizen science-based e-modules on biodiversity materials. This questionnaire assesses the ease of use, relevance of the material, and its impact on student understanding. Based on **Figure 2**, the results of the questionnaire show that 62% of students strongly agree with the use of e-modules based on measurements using the Likert scale. These results show that the e-modules developed are considered relevant and useful and are able to increase students' interest and involvement in the learning process. This is supported by the presentation of material that is clear, systematic, and easy to understand so that it is easier for students to understand the concepts learned. Thus, the e-modules developed can be declared effective in supporting the learning process and contributing positively to improving student learning outcomes.

These results show that e-modules are effective in improving student engagement and learning outcomes. Engaging and interactive learning media makes it easy to understand difficult concepts. This is in line with research

conducted by Jusuf (2021) and Kurniawan and Kuswandi (2021) the media and learning interests have a significant influence on learning outcomes, where the presentation of non-verbal material and increased interaction during learning have a positive impact on student achievement. E-modules can improve students' understanding with visuals and interactivity, as well as adapt the material to students' abilities. Whereas according to Amalia and Susiyawati (2023), Yulianci et al. (2021), Yuliansih et al. (2021), e-modules are designed for efficiency and effectiveness, e-modules include instructions, objectives, materials, assessments, glossaries, and references to support the achievement of learning outcomes.

CONCLUSION

The results of the study show that citizen science-based e-modules are very feasible to use based on the results of validation by material experts, media experts, linguists, and education practitioners. The results of the analysis using the Gregory formula show that all validators stated that the e-module is in the very feasible category, which is indicated by the value of the validity coefficient of 1. In addition, the calculation of CVR and CVI values also obtained a score of 1, which indicates an excellent level of content validity. The Mann-Whitney U test shows a significance value of 0.001 (< 0.05), so H_0 is rejected and H_1 is accepted. This proves that there is a significant difference in the improvement of learning outcomes in biodiversity materials. Citizen science-based electronic modules have been proven to be effective in learning biology and improving students' understanding. Students responded positively, showing that e-modules not only improve understanding, but also motivate them to learn. Therefore, e-modules can be considered an effective tool for creating an interactive and engaging learning environment, which is beneficial to the overall student learning experience.

Recommendations

Future researchers should explore citizen science-based electronic modules for other topics or levels of biology and assess their long-term impact on students' skills and attitudes. Practitioners are encouraged to use e-modules to support engaging and student-centered learning, while schools must provide adequate facilities and training for effective implementation.

Limitations

This research has several limitations. First, the e-module developed was only tested on one learning material, namely biodiversity, so its effectiveness on other biological materials is not yet known. Second, the trial was conducted in a limited time and on a relatively small number of samples, so results could not be generalized widely. Third, the implementation of citizen science in e-modules is still limited to simple observation and data collection, it has not yet reached the stage of in-depth data analysis by students.

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Ethics declaration: This research involved educational activities conducted in a school setting with the permission of the school administration. Student learning outcome data was analyzed anonymously, and no personally identifiable information was collected or disclosed. Therefore, in accordance with institutional and national regulations, formal ethics committee approval was not required. Participation in this study was voluntary, and the confidentiality of all participant data was maintained throughout the study.

AI statement: During the process of compiling this work, the authors did not use any generative AI tools.

Declaration of interest: Authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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APPENDIX A: PHOTOS OF THE STUDENTS



Figure A1. Photos of the students (the authors' own elaboration)

