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Development of Local Wisdom-Based Inquiry E-Module on Anaerobic Respiration to Improve Students' Science Process and Collaboration Skills in Phase F, State Senior High School 2 Plus Panyabungan

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Abstract: This study was designed to create an inquiry-based e-module that integrates local wisdom for learning the topic of Anaerobic Respiration. The aim was to ensure that this e-module is valid, practical, and effective in improving students' scientific process skills (SPS) and their ability to collaborate, especially for students in Phase F at SMA Negeri 2 Plus Panyabungan. The background of this study is based on the low level of scientific process skills, especially in connecting concepts (11%) and analyzing (24%), as well as weak collaboration skills (53.33% included in the low category). This study followed the research and development (R&D) method using the Plomp model, which consists of three phases: initial investigation, prototype development, and evaluation. The results showed that the developed e-module was highly valid, with an average score of 95.37%, very practical as indicated by student responses (93.01%) and teacher responses (97.92%), and effective in improving scientific process skills, evidenced by significant results (Sig. 0.000 < 0.05), and in improving student collaboration, which increased from the sufficient category to the very high category. Therefore, it can be concluded that this inquiry-based e-module that integrates local wisdom is suitable for use as an innovative learning resource to improve scientific process skills and collaboration among students studying Anaerobic Respiration.

Keywords: Anaerobic respiration; Collaboration; E-Module inquiry; Local wisdom; Science process skills

Introduction

Science Process Skills (SPS) are essential skills in science education, including biology. They involve skills such as observing, classifying, formulating hypotheses, designing experiments, analyzing data, and drawing conclusions. These skills not only enhance intellectual abilities but also help develop a scientific mindset (Salim et al., 2024; Limeri et al., 2020). In addition to SPS, collaboration skills are also a vital competency in the 21st century, as they enable students to work together in teams, share ideas, and solve problems collectively. However, teaching SPS and promoting collaboration in biology classrooms often faces challenges (Pratama et al., 2025). Learning typically emphasizes memorizing information rather than fostering a deep understanding of scientific processes (Morris, 2025; Darling-Hammond et al., 2024). There is also a lack of hands-on experience through practical activities.

Initial observations at SMA Negeri 2 Plus Panyabungan revealed that students had limited understanding of Science Process Skills, particularly in

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connecting related concepts (11%) and analyzing data (24%). These topics were considered abstract and difficult to relate to real-life situations. Furthermore, students' collaboration skills were also found to be low, with 53.33% categorized as having a low level of collaboration, caused by limited opportunities to engage in group work. Innovation in teaching materials is needed to address this issue. E-modules and other digital learning resources offer accessibility and flexibility (Zou et al., 2025; Afonso et al., 2025; Bashir & Lapshun, 2025). Students can actively participate in discovery, research, and problem-solving using inquiry-based learning approaches in e-modules, which have been shown to successfully enhance scientific process skills. Learning can become more relevant to students' daily lives when local knowledge is incorporated (Kamila et al., 2024; Petri et al., 2025).

The idea of anaerobic respiration can be linked to traditional Mandailing Natal knowledge, such as the fermentation process in common foods like bika ambon (alcohol fermentation) and dekke naniura (lactic acid fermentation). It is hoped that the e-module style, inquiry, and local knowledge will simultaneously enhance critical thinking and teamwork skills (Hidayat et al., 2023; Nazifah & Asrizal, 2022). Innovation in teaching materials is needed to address this issue. E-modules and other digital learning resources offer accessibility and flexibility (Afonso et al., 2025; Sari et al., 2024; Resmanti et al., 2024). Students can actively participate in discovery, research, and problem-solving using inquiry-based learning approaches in e-modules, which have been shown to successfully enhance scientific process skills (Wati & Syafriani, 2023; Arantika et al., 2019; Kassaye et al., 2025).

Learning can become more relevant to students' daily lives when local knowledge is incorporated (Ramli et al., 2025; Matindike & Ramdhany, 2025). The concept of anaerobic respiration can be connected to traditional knowledge of Mandailing Natal, such as the fermentation process in the common foods bika ambon (alcohol fermentation) and dekke naniura (lactic acid fermentation). It is hoped that the e-module style, inquiry, and local knowledge will simultaneously enhance critical thinking and teamwork skills. Based on the above background, this research was conducted with the aim of ensuring that this e-module is valid, practical, and effective in improving students' scientific process skills (SPS) and their ability to collaborate, especially for students in Phase F at SMA Negeri 2 Plus Panyabungan.

Method

This study used the Plomp development model and Research and Development (R&D) methodology. The Plomp model, which has three main steps, was chosen because of its methodical approach to creating instructional products through validation and efficacy testing: Phases 1, 2, and 3 include preliminary research, development or prototyping, and evaluation. Needs analysis through curriculum analysis, anaerobic respiration concept analysis, student and educator characteristics analysis, current teaching materials analysis, initial KPS and collaboration capabilities analysis, and literature review are all included in the first investigation phase. The prototype development phase follows Tessmer's formative evaluation flow, which consists of the following steps: initial prototype design (Prototype 1), self-evaluation (Prototype 2), expert review for validation of content, language, presentation, and graphic design (Prototype 2), one-on-one evaluation (Prototype 3) with three students with different abilities, and small group evaluation (Prototype 4) with six students with different abilities for initial practicality testing.

The assessment phase includes field testing to determine the practicality and effectiveness of the final product. The effectiveness test was conducted using a quasi-experimental design, specifically a Pretest-Posttest Non-Random Control Group Design. Two classes from Phase F (Grade 12) at SMA Negeri 2 Plus Panyabungan were selected through purposive sampling, considering similar academic abilities. One class was designated as the experimental group and used a local wisdom-based e-module (X), while the other class acted as the control group and followed conventional learning methods (O). Both classes took a pre-test (T1) and a post-test (T2) to measure their KPS performance.

The research instruments used included: an expert validation form to assess the feasibility of the e-module, a practicality questionnaire distributed to teachers and students in both small and large groups, a KPS observation sheet to monitor learning activities, a KPS test in the form of multiple choice questions (a total of 20 questions) that had undergone validation and reliability testing (with a reliability score of 0.82, which is very high), and a questionnaire to evaluate collaboration skills. The validity and practicality of the data were assessed using descriptive percentage statistics based on a Likert scale, with categories determined according to Riduwan's criteria. In general, the procedure for developing an e-inquiry module based on local wisdom can be seen in Figure 1.

Observational data from the KPS were analyzed using average scores and categorized accordingly. The KPS test results, including pretest and posttest scores, were checked for effectiveness after ensuring the data met the required conditions of normality (Shapiro-Wilk test) and homogeneity (Levene's test). Hypotheses were

then tested using an independent sample t-test with SPSS version 25.0, at a significance level of α = 0.05. Collaboration questionnaire data were analyzed using percentages and categorized according to Hendrayana's criteria.

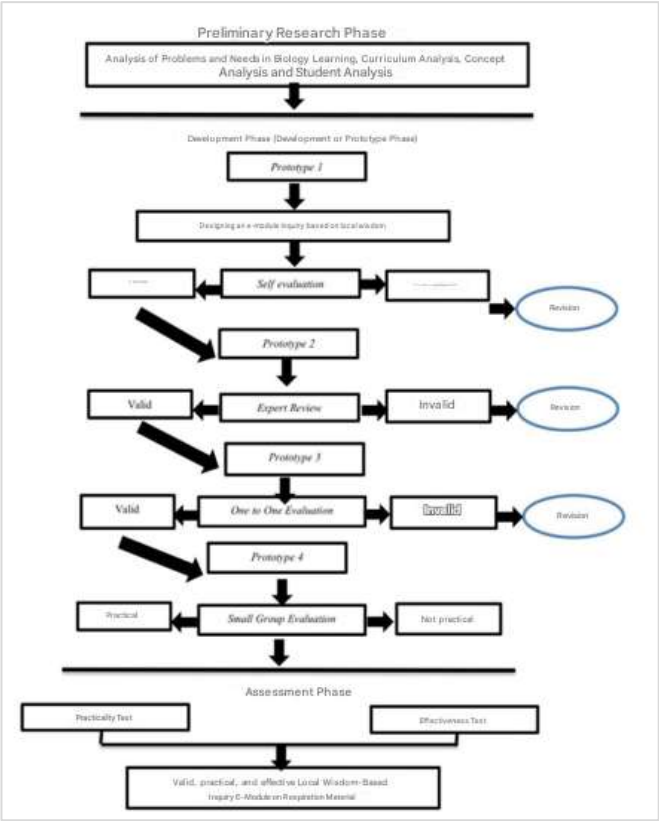

Figure 1. Procedure for developing an inquiry e-module based on local wisdom to improve the science process and collaboration skills of phase F students of SMA Negeri 2 Plus Panyabungan

Result and Discussion

This local wisdom-based e-module focusing on anaerobic respiration was validated by six validators consisting of four expert lecturers and two practicing teachers. The validation results showed that the module obtained an overall average score of 95.37%, which is included in the "Very Valid" category. The evaluation was carried out on four aspects: content feasibility, language, presentation, and graphics. Each aspect was assessed as follows: Content Feasibility received a score of 95.42% (Very Valid), Language received a score of 94.17% (Very Valid), Presentation received a score of 94.55% (Very Valid), and Graphics received a score of 97.33% (Very Valid). Based on the feedback provided by the validators, minor revisions were made to the prototype. The following is the product generated by the research on the local wisdom-based inquiry module.

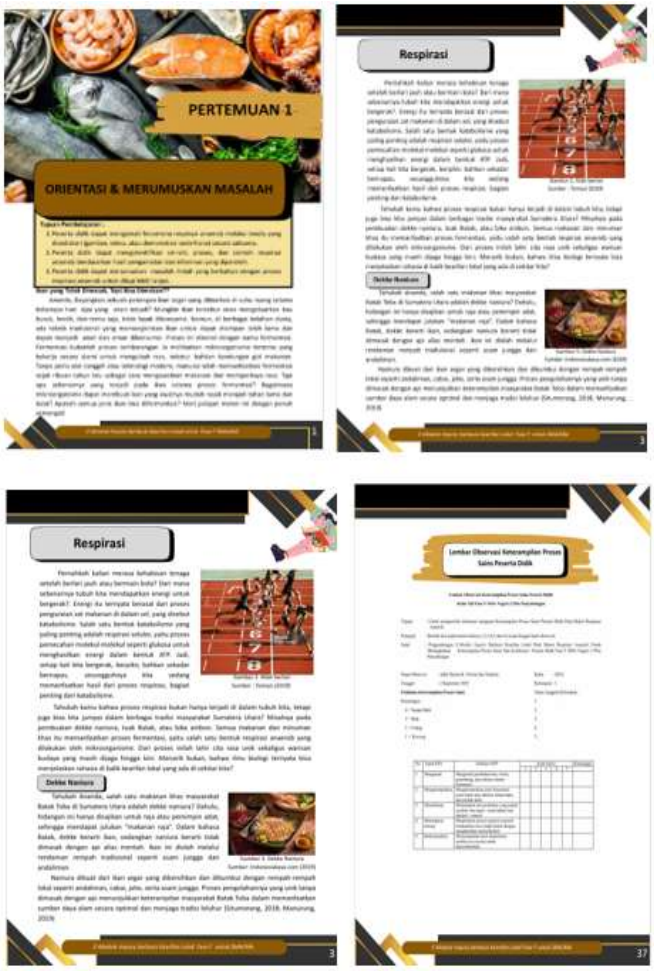

Figure 2. Product generated by the research on the local wisdom-based inquiry module

E-Module Practicality:

Small Group Test: Responses from six students showed an average practicality score of 96.18%, meeting the "Very Practical" standard. The aspects of attractiveness (98.96%), ease of use (95.83%), and usefulness (93.75%) were all considered very practical; Field Test: Feedback from 31 students in the larger group showed an average practicality score of 93.01%, also falling into the "Very Practical" category. The aspects of attractiveness (92.74%), ease of use (93.15%), and usefulness (93.15%) were similarly rated as very practical; Teacher Response: Input from biology teachers resulted in an average practicality score of 97.92%, meeting the "Very Practical" criteria. The aspects of attractiveness (100%), ease of use (100%), and usefulness (93.75%) were all considered very practical.

Effectiveness of E-Module:
Science Process Skills (SPS)

The results of the KPS observations showed that the average score of the experimental class (3.55, Very Good

criteria) was higher than that of the control class (2.04, Fairly Good criteria); The results of the KPS test showed that the average posttest score of the experimental class (87.61) was significantly higher than that of the control class (73.10); The prerequisite test shows that the posttest data for both classes are normally distributed (Sig. > 0.05) and have homogeneous variance (Sig. 0.137 > 0.05); The results of the t-test (Independent Samples t-test) show a Sig. (2-tailed) value of 0.000 < 0.05, which means H0 is rejected and H1 is accepted. There is a significant difference in KPS between the experimental class and the control class after treatment; Collaboration Skills: The assessment of the effectiveness regarding students' collaboration skills was obtained using a questionnaire instrument. Based on the results, there was an increase in collaboration skills in both classes. However, the average posttest score in the experimental class (90.39) with the "Very High" criterion was superior to that of the control class (80.50) with the "High" criterion. This difference in averages indicates that the improvement in collaboration skills in the experimental class was greater.

Before the hypothesis test was conducted, the posttest data for collaboration skills had fulfilled the prerequisite tests. The results of the normality test using the Shapiro-Wilk test showed that the data were normally distributed, with significance values of 0.097 (control) and 0.156 (experimental), both of which were > 0.05. The homogeneity test results also indicated that the data had a homogeneous variance, with a significance value of 0.353 (> 0.05); Given that the data were normal and homogeneous, a hypothesis test (t-test) was performed to determine the difference in effectiveness. The result of the hypothesis test yielded a Sig. (2-tailed) value of 0.003. Since the significance value of 0.003 is < 0.05, H1 was accepted. Based on this analysis, it can be concluded that there is a significant difference between the average collaboration skills of the control class and the experimental class. This proves that the use of the inquiry-based e-module integrated with local wisdom on the topic of anaerobic respiration has a significant effect on improving the collaboration skills of Phase F students at SMA Negeri 2 Plus Panyabungan.

Discussion

The results of the study indicate that the inquiry-based e-module on anaerobic respiration, developed using local wisdom, meets the criteria of validity, practicality, and effectiveness. A high validity score of 95.37% indicates that the e-module is appropriate in terms of content, curriculum alignment, language, presentation of material according to the inquiry format, and use of graphics (Utami et al., 2024; Abdullah et al., 2025). This validity is crucial because it ensures the e-module is suitable for use in teaching and learning activities. The e-module also demonstrated a very high level of practicality, as reflected in the positive responses from students and teachers. Student feedback, both in small groups (96.18%) and large groups (93.01%), as well as teacher feedback (97.92%) highlighted that the e-module was user-friendly, engaging, time-efficient, and beneficial for learning. The e-module's appeal was enhanced by the use of visual elements such as images and videos, as well as its attractive design, which aligns with learners' preferences for digital and interactive resources (Riasri et al., 2025; Apriyani et al., 2025). Its ease of use was further supported by clear instructions and a well-organized structure. Benefits include encouraging independent learning and improving understanding of the subject matter, which aligns with the goal of creating effective teaching materials (Ribosa & Duran, 2022; Kim et al., 2019).

The e-module proved effective, evidenced by significant improvements in students' scientific process skills (SPS) and collaboration abilities in the experimental group compared to the control group (Wardani et al., 2025; Aliyah et al., 2025). The improvements in SPS, supported by observational data and test results, indicate that the structured inquiry approach used in the e-module successfully helped students engage in key scientific activities such as observing, interpreting, applying concepts, and communicating. These findings align with previous research highlighting the positive effects of the inquiry model on scientific process skills (Sa'adah et al., 2023; Doyan et al. 2020; Muhamad Dah et al., 2024). Incorporating local wisdom, such as the traditional fermentation practices of dekke naniura and bika ambon, makes the abstract topic of anaerobic respiration more understandable and meaningful (Linder, 2024; Barrow et al., 2015; Pang et al., 2023). This contextual approach helps students connect theoretical knowledge to real-life events, addressing previously weak areas in their scientific process skills.

The significant improvement in collaborative skills in the experimental group, which met the "Very High" standard, indicates that group-based activities in the e-module, such as discussions, collaborative experiments (Chen et al., 2023; Aifan, 2022), and presentations of results, effectively foster positive teamwork, clear division of tasks, and shared responsibility among students. These results align with existing research that emphasizes the ability of the inquiry model to strengthen collaboration through social engagement and cooperative learning (Ningsih et al., 2025; Zhang et al., 2023; Seprie et al., 2025). Furthermore, the use of local wisdom in the learning process also contributes to the formation of a sense of community and cultural awareness among students. However, this study has limitations, namely that it was only conducted in one school and there is a need for adaptation time for

students who are not yet accustomed to the e-module format and inquiry learning (Sotiriou et al., 2020; Sihombing & Yohandri, 2025).

Conclusion

Based on the results of research and discussion, it can be stated that: The inquiry-based e-module incorporating local wisdom for Anaerobic Respiration learning meets highly valid criteria as determined by expert evaluation. This assessment covers aspects such as content suitability, language clarity, presentation quality, and use of visual elements; The inquiry-based e-module, which incorporates local wisdom for Anaerobic Respiration learning, also meets highly practical criteria, as demonstrated by feedback from teachers and students. This feedback considers factors such as the module's appeal, ease of use, and the benefits it offers in the learning process; Inquiry-based e-modules that integrate local wisdom for Anaerobic Respiration learning have proven effective in improving students' science process skills and collaboration abilities in Phase F of SMA Negeri 2 Plus Panyabungan. Therefore, this e-module is suitable for use as an innovative learning resource for the topic of Anaerobic Respiration. It combines a scientific approach with a local cultural context, making it a valuable tool for education.

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Conceptualization; methodology.; validation; R. P; formal analysis; investigation; M. F.; resources; data curation; writing—original draft preparation; H.; writing—review and editing.; visualization: F. A. All authors have read and agreed to the published version of the manuscript.

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