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Design Gap Analysis of Sustainability-Oriented Biology Teaching Modules among Pre-Service Teachers Using Project-Based Learning Analytics

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ABSTRACT

This study investigates the use of project-based learning analytics as a diagnostic approach to identify gaps between administrative completion and conceptual design quality in sustainability-oriented biology teaching modules developed by pre-service biology teachers. Participants were 63 pre-service biology teachers from two classes (5A = 30 students; 5B = 33 students), who produced 13 group teaching modules. Data included project scores, formative scores, midterm and final examination scores, project-component records, questionnaire responses, and design-gap rubric scores. The data were analyzed using descriptive statistics, comparison between administrative and conceptual components, and percentage-based design-gap analysis across curriculum alignment, assessment design, digital pedagogy, deep learning, and sustainability integration. Results showed that overall student performance was relatively good and homogeneous, with a mean final score of 81.34 and a standard deviation of 2.23. However, full administrative completion of project drafts and progress reports (100.00%) did not correspond to conceptual design quality. The final teaching modules achieved only 34.90% of the target criteria for coherent integration of module components. The largest design gap was found in sustainability integration (76.90%), followed by deep learning (69.20%), assessment design (61.50%), digital pedagogy (53.80%), and curriculum alignment (46.20%). These findings indicate that project completion does not automatically ensure coherent instructional design. This study contributes by demonstrating that project-based learning analytics can reveal hidden weaknesses in sustainability-oriented instructional design that *are not captured by final grades or document completion alone. The findings highlight the need for operational rubrics, formative feedback, model modules, and explicit design scaffolding.*

INTRODUCTION

Sustainability has become a central issue in science education because schools are no longer expected merely to prepare learners to understand scientific concepts, but also to use such knowledge critically and responsibly in responding to climate change, pollution, ecosystem degradation, and biodiversity loss. The sustainable development agenda and environmental education policies have encouraged science learning to become more contextual, inquiry-based, action-oriented, and relevant to real socio-environmental problems (Birkett et al., 2023; Hogan & O'Flaherty, 2021; Menzie-Ballantyne & Ham, 2021). In this context, biology education occupies a strategic position because concepts such as ecosystems, conservation, biodiversity, organism interactions, and environmental change are central to biology learning and are directly related to sustainability issues. Therefore, sustainability-oriented biology learning needs to be designed not only as content delivery, but also as a coherent pedagogical process that connects scientific concepts with environmental responsibility and student action.

Biology education is expected to develop environmental literacy, ecological awareness, and learners' ability to make evidence-based decisions. Biology learning designed through inquiry, citizen science, socioscientific issues, and real environmental activities has been shown to strengthen students' environmental knowledge, attitudes, and behavior (Rasis et al., 2023; Eze et al., 2022; Hokayem & Jin, 2019). However, pre-service biology teachers may still have conceptual gaps related to environmental and climate issues. Therefore, teacher education needs to provide learning experiences that not only strengthen conceptual understanding but also train pre-service teachers to design sustainability-oriented biology learning in a structured manner (Rasis et al., 2023; Eze et al., 2022). This need is especially important because pre-service teachers are expected to transform sustainability ideas into teachable objectives, learning activities, assessment tasks, and learning media.

The main problem underlying this study is the limited attention given to the conceptual quality of instructional designs developed by pre-service biology teachers. Strengthening sustainability-oriented teacher education cannot be achieved simply by adding environmental topics to coursework or by asking students to complete instructional planning formats. Pre-service teachers need to be trained to connect biology content, learning objectives, assessment, technology, and sustainability issues within a coherent instructional design. Previous studies have shown that the implementation of sustainability education remains uneven due to resource limitations, policy alignment issues, and tensions between mastery of scientific concepts and action-oriented pedagogy (Boon, 2024; Damoah & Omodan, 2023; Molefe & Aubin, 2023; Perkkilä & Joutsenlahti, 2021). However, these studies have paid less direct attention to how pre-service teachers' completed instructional products reveal the difference between procedural completion and conceptual coherence. This unresolved issue becomes the specific gap addressed in this study.

One way to address this problem is through a teaching-module development project. A teaching module can show how pre-service teachers translate the curriculum, biological concepts, assessment, media, and learning activities into a design that can be used in the classroom. A teaching module can also serve as a learning product for assessing the quality of pre-service teachers' design reasoning. In the context of this study, students were asked to develop senior high school biology teaching modules that included learning outcomes, learning objectives, sequences of learning objectives, initial assessment, formative assessment, summative assessment, teaching materials, student worksheets, technology-based media, and deep-learning strategies. However, the completeness of project documents does not necessarily indicate strong instructional design quality. A module may appear complete in terms of format but remain weak in curriculum alignment, assessment coherence, meaningful technology use, deep learning, and sustainability integration. In this study, this condition is defined as an administrative–conceptual design gap, namely the difference between the completion of required project documents and the quality of conceptual integration among objectives, content, activities, assessment, technology, and sustainability issues.

The literature emphasizes that pre-service biology teachers require pedagogical content knowledge that connects biological concepts with sustainability goals, socioscientific issues, and scientific inquiry (Mafugu, 2022; Mientus et al., 2022). Such competence needs to be complemented by climate change knowledge, curriculum alignment skills, assessment literacy, and technological competence so that the teaching modules developed are not only complete but also coherent and meaningful (Zikra et al., 2024; Maharika et al., 2020; Masoumi, 2020). Theoretically, this study is informed by instructional design and constructive alignment, which emphasize coherence among objectives, activities, and assessment; by TPACK, which explains the pedagogical use of technology; by learning analytics, which supports evidence-based diagnosis of learning products; and by sustainability pedagogy, which links biological concepts with socio-environmental action. Thus, the quality of a teaching module should be examined not only through the presence of its components but also through the interconnections among objectives, activities, assessment, media, and sustainability issues.

Previous studies have examined the development of media, teaching materials, modules, and pedagogical content knowledge in teacher education. However, studies that specifically distinguish administrative completion of project tasks from the conceptual quality of sustainability-oriented biology teaching module design remain limited. Several studies have also shown that sustainability integration, assessment alignment, and technology use in pre-service teachers' instructional design are still uneven (Kildė, 2024; Lam, 2024; Hinson et al., 2023; Arrieta, 2020). Accordingly, this study uses project-based learning analytics to trace project scores, component completion, questionnaire responses, and rubric-based module quality as connected evidence of design performance. This gap provides the basis for using project-based learning analytics as a diagnostic approach to examine the difference between administrative compliance and conceptual design quality.

This study aims to analyze design gaps in sustainability-oriented pre-service biology teacher education through project-based learning analytics. The novelty of the study lies in its attempt to distinguish administrative completion of project tasks from the conceptual quality of teaching-module design, which is conceptualized in this study as an administrative–conceptual design gap. Specifically, this study examines students' performance profiles, compares administrative and conceptual components, and identifies design gaps in curriculum alignment, assessment design, digital pedagogy, deep learning, and sustainability integration. By doing so, this study contributes to sustainability-oriented biology teacher education by offering a more specific diagnostic lens for evaluating teaching-module development beyond grades and document submission.

METHOD

Research Design

This study employed a descriptive-evaluative learning analytics design with a project-based learning analytics approach. This design was used to map the performance of pre-service biology teachers in a teaching-module development project, distinguish administrative completion from conceptual design quality, and identify design gaps in sustainability-oriented teaching modules. The learning analytics approach is relevant because it can connect process data and outcome data to examine the development of design competence in project-based learning (Delen et al., 2024; Lasekan et al., 2020). In teacher education, this approach can also help reveal patterns of design decisions, product achievement, and instructional design areas that require strengthening (Batuchina et al., 2023)

A descriptive-analytical design was selected because this study did not aim to test a specific treatment. Instead, it sought to describe patterns of student achievement and analyze the differences between project completeness and the conceptual quality of teaching modules. Thus, project-based learning analytics was used as a diagnostic approach to examine the relationships among student performance, project components, and the quality of the teaching modules produced. Operationally, the analytics process connected three forms of evidence: student performance data, project-component completion records, and rubric-based evaluation of teaching-module quality.

Research Context

The study was conducted in a Biology Learning Planning Workshop course. In this course, pre-service biology teachers developed senior high school biology teaching modules based on the Indonesian Merdeka Curriculum. The project involved analysis of learning outcomes, development of learning objectives, sequencing of learning objectives, initial assessment, formative assessment, summative assessment, teaching materials, student worksheets, technology-based media, and deep-learning strategies. Sustainability orientation was expected to appear through the integration of environmental issues, biodiversity, conservation, ecosystems, or Sustainable Development Goals into learning objectives, activities, assessment, and teaching materials.

This context was selected because teaching modules can demonstrate how pre-service teachers connect biology content, pedagogy, assessment, technology, and sustainability issues into a coherent instructional design. Teaching modules can also be used as learning products to assess the quality of pre-service teachers' design reasoning. The literature indicates that instructional design quality should be examined through the alignment of objectives, activities, assessment, technology use, and sustainability integration (Van der Waldt, 2024; Haseski, 2019).

Participants and Units of Analysis

The participants were 63 pre-service biology teachers from two classes: Class 5A with 30 students and Class 5B with 33 students. The students worked in groups to develop senior high school biology teaching modules. The groups followed the regular course project arrangement, in which each group was responsible for producing one complete teaching module under lecturer supervision. This process resulted in 13 group teaching modules, which were used as the primary products in the design-gap analysis.

Student identities were anonymized because the analysis was not intended to evaluate specific individuals but to examine collective patterns of achievement in teaching-module development. The units of analysis in this study were divided into two levels. First, learning performance was analyzed at the student level based on project scores, formative scores, midterm examination scores, final examination scores, and final grades. Second, design quality was analyzed at the group teaching-module level based on the design-gap rubric applied to the 13 modules produced.

This distinction between units of analysis is important to avoid inaccurate interpretation of the data. Student performance data describe overall achievement in project-based learning, whereas teaching-module data show the conceptual quality of learning products developed collaboratively in groups. The 13 group modules were therefore treated as the main unit for design-gap analysis because the final module was a collaborative product, not an individual assignment.

Data Sources

The data sources consisted of three groups. First, project-based learning performance data included project scores, formative scores, midterm examination scores, final examination scores, and final grades. These data were used to construct the general profile of student performance.

Second, data on administrative and conceptual project components were collected. Administrative components included the submission of project drafts and progress reports. Conceptual components included Student Worksheets (SW) 1 to 4 and the final teaching module. SW 1 focused on curriculum analysis, SW 2 on initial module design, SW 3 on document and media development, and SW 4 on module-component integration. These data were used to compare the level of administrative completion with conceptual design quality. Administrative completion refers to whether the required documents were submitted, whereas conceptual design quality refers to the extent to which the module components were coherently connected.

Third, questionnaire data and design-gap rubric data were used to identify gaps in five categories: curriculum alignment, assessment design, digital pedagogy, deep learning, and sustainability integration. The use of multiple data sources is consistent with project-based assessment, which combines rubric scores, design products, process notes, and self-reports to assess instructional design competence (Knogler et al., 2025; Zakeri et al., 2023; Drost & Levine, 2021; Schissel & Reyes, 2020). Questionnaire responses were used as supporting evidence, while rubric scores served as the main basis for classifying design gaps.

Table 1. Data Sources, Units of Analysis, and Analytical Functions

Data Source	Unit of Analysis	Analytical Function
Project score, formative score, midterm examination, final examination, and final grade	63 students	Describing the overall profile of student performance in project-based learning.
Project drafts, progress reports, SW 1–SW 4, and final teaching module	Students and project components	Comparing administrative completion with conceptual design quality by distinguishing document submission from module-design coherence.
Questionnaire and design-gap rubric	13 group teaching modules	Identifying design gaps in curriculum alignment, assessment design, digital pedagogy, deep learning, and sustainability integration using rubric scores as primary evidence and questionnaire responses as supporting evidence

Instruments

The research instruments consisted of a project-based learning analytics questionnaire and a design-gap rubric for biology teaching modules. The questionnaire was used to obtain supporting information regarding administrative completion, curriculum alignment, assessment design, digital pedagogy, deep learning, and sustainability integration. Each questionnaire item used a five-point Likert scale, ranging from strongly disagree to strongly agree. The questionnaire was used to strengthen the interpretation of project performance data, not to replace the assessment of teaching-module products.

The design-gap rubric was used to assess the conceptual quality of the teaching modules. The rubric covered five main categories: curriculum alignment, assessment design, digital pedagogy, deep learning, and sustainability integration. Curriculum alignment was assessed based on the relationship among learning outcomes, learning objectives, sequences of learning objectives, learning activities, and assessment. Assessment design was assessed based on coherence between learning objectives and initial, formative, and summative assessments. Digital pedagogy was assessed based on the connection between digital media or tools and objectives, activities, worksheets, and assessment. Deep learning was assessed based on the presence of activities involving analysis, reflection, problem solving, and concept application. Sustainability integration was assessed based on the connection between environmental issues, biodiversity, conservation, ecosystems, or the Sustainable Development Goals and learning objectives, activities, and assessment. Each category was scored using a rubric scale, and a lower score indicated weaker conceptual integration in the teaching module.

Instrument development followed principles of educational instrument design, including construct clarity, content validity through expert review, readability testing, and reliability analysis. Content validity was examined through expert judgment to ensure the appropriateness of items for the constructs being measured. The expert review focused on item relevance, clarity, construct representation, and suitability for sustainability-oriented biology module assessment. Questionnaire reliability was examined using Cronbach's alpha coefficient before the data were used in the main analysis. An alpha coefficient at or above the accepted internal-consistency criterion was considered adequate for supporting the interpretation of questionnaire responses.

Table 2. Operational Criteria for Rubric Scoring and Design-Gap Classification

Category	Analytical Focus	Main Evidence	Gap Criterion
Curriculum alignment	Coherence among learning outcomes, objectives, sequences of objectives, activities, and assessment	Final module, SW 1, SW 4	A gap was identified when alignment was incomplete or when the category score was below the expected coherence target.
Assessment design	Coherence between objectives and initial, formative, and summative assessments	Final module, SW 2, SW 4	A gap was identified when assessment tasks were present but did not directly measure the stated learning objectives or sustainability competencies.
Digital pedagogy	Pedagogical integration of digital tools with activities, worksheets, and assessment	Final module, SW 3, SW 4	A gap was identified when digital media functioned mainly as presentation support rather than as part of the learning strategy.
Deep learning	Analysis, reflection, problem solving, argumentation, and concept application	Final module, SW 4	A gap was identified when activities emphasized task completion but provided limited opportunities for higher-order thinking or transfer.
Sustainability integration	Integration of environmental issues, biodiversity, conservation, ecosystems, or SDGs into objectives, activities, and assessment	Final module, SW 1–SW 4	A gap was identified when sustainability appeared only as an additional example or context and was not integrated into the core instructional design.

Data Analysis

Data analysis was conducted in three stages. The first stage involved descriptive statistical analysis, including mean, minimum score, maximum score, standard deviation, and percentage of target achievement. This analysis was used to describe the overall profile of student performance in project-based learning. Target achievement was defined as the proportion of students or group products that reached the minimum course target for each assessed component, while partial achievement indicated performance below that target.

The second stage involved comparative analysis between administrative and conceptual components. Administrative components were analyzed based on the completion of project-draft and progress-report submissions. Conceptual components were analyzed based on achievement in SW 1 to SW 4 and the final teaching module. This comparison was used to identify whether project completeness was aligned with the quality of the instructional design produced. Because the purpose of the study was diagnostic rather than experimental, the comparison focused on the magnitude and pattern of achievement across components rather than on treatment effects.

The third stage involved design-gap analysis based on rubric scores and supporting questionnaire data. Design gaps were determined in five categories: curriculum alignment, assessment design, digital pedagogy, deep learning, and sustainability integration. A module was categorized as having a design gap when the rubric evidence showed incomplete conceptual integration in the relevant category, as clarified in Table 2. The percentage of design gaps was calculated based on the number of group teaching modules showing a gap in each category compared with the total of 13 teaching modules analyzed as shown in equation (1).

$$\text{Percentage of design gap} = \frac{\text{Number of modules with a gap in each category}}{\text{Total number of modules analyzed}} x\ 100\% \quad (1)$$

Using that equation (1), the percentage of design gaps indicates the proportion of teaching modules that still require strengthening in each category. This analysis was used to identify areas of design requiring more targeted improvement, particularly in curriculum alignment, assessment, digital pedagogy, deep learning, and sustainability integration. Questionnaire data were integrated at the interpretation stage to support, confirm, or contextualize the rubric-based findings.

RESULTS AND DISCUSSION

This section presents the results of the data analysis to show that project-based learning analytics can reveal design gaps in sustainability-oriented biology teaching modules. The results focus on three aspects: the overall profile of student performance, the comparison between administrative completion and conceptual design quality, and the categories of design gaps emerging in the teaching modules. The performance profile was analyzed using data from 63 students, whereas the design gaps were analyzed using 13 group teaching modules. This distinction is important so that results based on student scores and results based on the quality of teaching-module products can be interpreted accurately. The results are therefore presented as diagnostic evidence, not merely as descriptive score reporting.

Project-Based Learning Performance

The overall profile of student performance is presented in Table 3. The data show that student performance in the two classes was relatively good and homogeneous. The overall mean final score was 81.34, with a minimum score of 76.40, a maximum score of 84.80, and a standard deviation of 2.23. Class 5B obtained a slightly higher mean final score than Class 5A, namely 81.58 compared with 81.08. Because the difference between the two classes means was only 0.50 points, the scores indicate a stable pattern of achievement rather than a substantial class-level difference.

Table 3. Overall Profile of Project-Based Learning Performance among Pre-Service Biology Teachers

Class	n	Mean final grade	Minimum	Maximum	SD	Mean project score	Mean formative score	Mean final exam
5A	30	81.08	76.80	84.60	2.16	83.17	80.94	82.41
5B	33	81.58	76.40	84.80	2.28	83.46	81.63	82.77
Total	63	81.34	76.40	84.80	2.23	83.32	81.30	82.60

The mean project scores also showed a similar pattern. Class 5A obtained a project score of 83.17, whereas Class 5B obtained a project score of 83.46. The formative, midterm, and final examination scores were likewise close across the two classes, confirming that the student-level achievement profile was relatively consistent. These findings indicate that, in general, students were able to follow project-based learning with relatively stable achievement. However, the final-score and project-score profiles were not sufficient to explain the quality of teaching-module design. Homogeneous scores may describe students' overall performance, but they do not show whether the teaching modules demonstrate curriculum alignment, coherent assessment, meaningful technology use, deep learning, and sustainability integration. Therefore, the analysis was continued by comparing administrative and conceptual project components.

Administrative Completion and Conceptual Design Quality

The comparison between administrative and conceptual components is presented in Table 4 and visualized in Figure1. The administrative components, namely project-draft submission and progress reports, all reached a mean score of 100.00 with 100.00% target achievement. This shows that students fully met the project schedule and structure. However, the conceptual components showed lower achievement and a gradual decline from SW 1 to the final teaching module. In this section, target achievement refers to the proportion of project components or group products that met the expected course target, whereas partial achievement refers to components that remained below that target.

Table 4. Administrative Completion and Conceptual Design Quality across Project Components

Dimension	Project component	Mean score	Target achievement (%)	Partial achievement (%)
Administrative completion	Project draft	100.00	100.00	0.00
Administrative completion	Progress report 1	100.00	100.00	0.00
Administrative completion	Progress report 2	100.00	100.00	0.00
Administrative completion	Progress report 3	100.00	100.00	0.00
Administrative completion	Progress report 4	100.00	100.00	0.00
Conceptual design quality	SW 1: curriculum analysis	83.90	82.50	17.50
Conceptual design quality	SW 2: initial module design	82.10	76.20	23.80
Conceptual design quality	SW 3: documents and media	79.80	69.80	30.20
Conceptual design quality	SW 4: module integration	77.60	63.30	36.70
Conceptual design quality	Final teaching module	76.90	34.90	65.10

In the conceptual components, SW 1 reached 82.50% target achievement, which then decreased to 76.20% in SW 2, 69.80% in SW 3, and 63.30% in SW 4. The sharpest decline occurred in the final teaching module, which reached only 34.90% target achievement. This decline is the clearest evidence of the administrative–conceptual design gap because the final product required students to integrate all previous components into a coherent module. This pattern indicates a difference between administrative completion and conceptual design quality. In other words, students were able to complete project documents, but not all groups were able to integrate the learning components into coherent teaching modules. This finding supports the view that task completion is not always equivalent to meaningful learning because design quality requires evidence of transfer, deep reasoning, pedagogical justification, and the ability to connect different learning components (Martínez-Pérez et al., 2022; Luo & Ye, 2021). As shown in Figure 1, the line between administrative and conceptual achievement separates strongly at the final module stage, indicating that document submission alone cannot represent instructional design quality. Figure 1 clarifies that full administrative achievement was not followed by equivalent conceptual quality across Project Components.

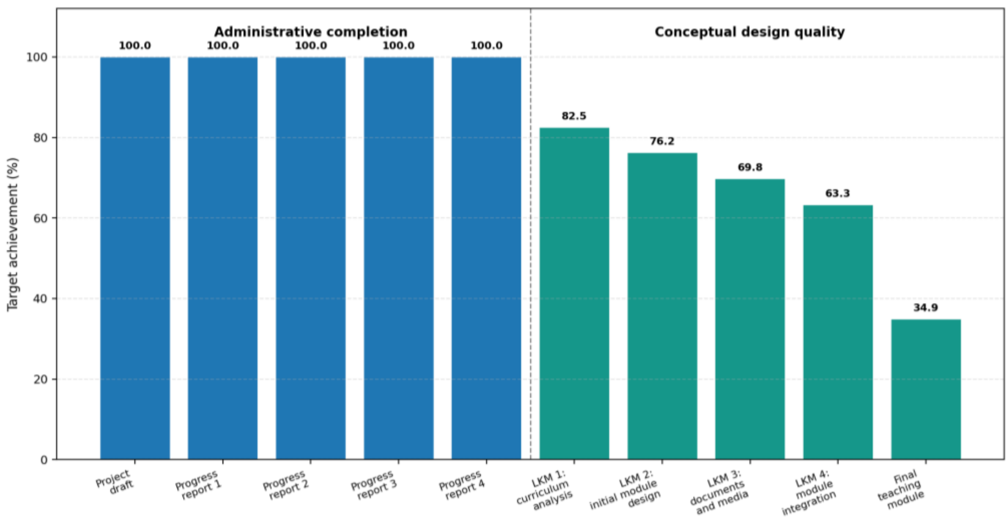

Fig.1. Administrative completion versus conceptual design quality

Design Gaps in Sustainability-Oriented Biology Teaching Modules

Rubric analysis of the 13 group teaching modules showed five categories of design gaps, as presented in Table 5. The largest gap was found in sustainability integration, which occurred in 76.90% of the modules, with a mean rubric score of 2.39. This indicates that environmental issues, biodiversity, conservation, ecosystems, or the Sustainable Development Goals were not consistently positioned as the main orientation of learning. Instead, sustainability tended to appear as a topic or example rather than as an organizing principle connecting objectives, activities, and assessment. This condition is consistent with findings showing that sustainability integration in biology learning is often implicit and not yet systematically connected to objectives, activities, and assessment (Isac et al., 2022; Hassan et al., 2020; Gopalakrishnan et al., 2019).

Table 5. Design Gaps in Sustainability-Oriented Biology Teaching Modules

Category	Indicator	Mean score	Modules	%
Curriculum alignment	Alignment among learning outcomes, objectives, sequences of objectives, activities, and assessment	2.85	6	46.20
Assessment design	Coherence between objectives and initial, formative, and summative assessments	2.69	8	61.50
Digital pedagogy	Pedagogical integration of digital tools	2.77	7	53.80
Deep learning	Analysis, reflection, problem solving, and concept application	2.54	9	69.20
Sustainability integration	Environmental issues, biodiversity, conservation, ecosystems, or SDGs	2.39	10	76.90

The deep-learning gap appeared in 69.20% of the modules. This finding shows that some modules still emphasized the completion of activities rather than conceptual engagement that promotes analysis, reflection, problem solving, and concept application. The assessment-design gap appeared in 61.50% of the modules. This means that assessment tools were available, but they were not always aligned with learning objectives and sustainability competencies. The digital-pedagogy gap appeared in 53.80% of the modules. Digital media had been used, but they did not always function as part of a learning strategy connected to objectives, activities, worksheets, and assessment. The curriculum-alignment gap appeared in 46.20% of the modules, indicating that nearly half of the modules still required strengthening in the connection among learning outcomes, objectives, sequences of objectives, activities, and assessment. The pattern shows that the most serious problems were not the absence of module components, but weak functional alignment among those components.

To clarify the basis for the percentage calculations in Table 5, a summary of the units of analysis and the number of modules with gaps is presented in Table 6. Percentages were calculated based on the number of modules showing a gap in each category compared with the total of 13 group teaching modules analyzed. Table 6 is simplified to avoid repetition by presenting only the calculation basis needed to verify the percentages reported in Table 5.

Table 6. Clarification of the Unit of Analysis and Basis for Calculating Design-Gap Percentages

Category	Unit	Analyzed	With gaps	Formula	%
Curriculum alignment	Group teaching modules	13	6	6/13 × 100	46.20
Assessment design	Group teaching modules	13	8	8/13 × 100	61.50
Digital pedagogy	Group teaching modules	13	7	7/13 × 100	53.80
Deep learning	Group teaching modules	13	9	9/13 × 100	69.20
Sustainability integration	Group teaching modules	13	10	10/13 × 100	76.90

Table 7 shows that the main weaknesses of the teaching modules lie in design coherence, not merely in the completeness of components. Learning outcomes, objectives, activities, and assessments were already included, but they were not always well aligned. Assessments did not fully measure the intended objectives and sustainability competencies. Digital technology was still mainly used for presentation, while learning activities tended to focus on worksheet completion. Sustainability issues also appeared as additional themes. Therefore, the modules need stronger coherence, pedagogy, reflection, and student-oriented action.

Table 7. Examples of Common Design Weaknesses Identified in the Teaching Modules

Category	Common Weakness
Curriculum alignment	Learning outcomes, objectives, activities, and assessments were listed but not always connected in a clear instructional sequence.
Assessment design	Initial, formative, and summative assessments were available, but some tasks did not directly measure the intended objectives or sustainability competencies.
Digital pedagogy	Digital tools were used mainly as presentation media and were not consistently linked to inquiry, collaboration, feedback, or assessment.
Deep learning	Several activities emphasized completing worksheets rather than analyzing problems, reflecting on evidence, or applying biological concepts to real contexts.
Sustainability integration	Sustainability appeared mainly as a theme or example rather than as a core orientation embedded in objectives, activities, assessment, and student action.

The project-based learning analytics framework in Figure 2 summarizes the project-based learning analytics framework used to interpret these findings. The framework shows that performance data, project-component data, and questionnaire and rubric data can be integrated to identify design areas requiring strengthening. Figure 2 therefore connects the three layers of analysis: student achievement, project-component achievement, and rubric-based design-gap evidence. These findings confirm that the development of sustainability-oriented teaching modules should not be assessed only through document completeness, but also through conceptual coherence, assessment quality, digital pedagogy, deep learning, and sustainability integration. Thus, the results show that project-based learning analytics can reveal differences among administrative achievement, conceptual achievement, and design gaps in learning products.

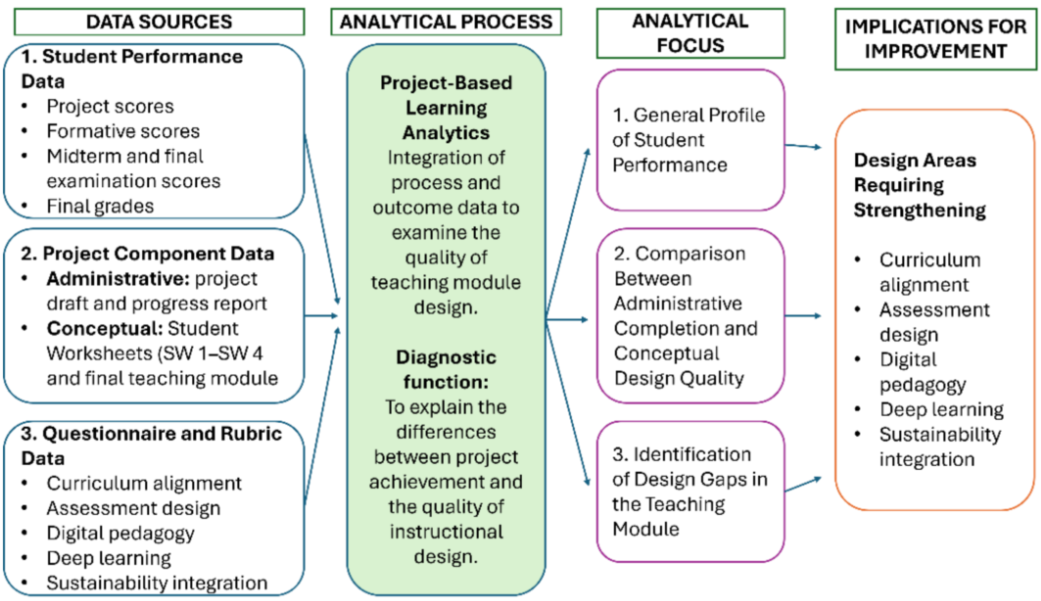

Fig.2. Project-based learning analytics framework for revealing design gaps

Discussion of Design-Gap Findings

The findings of this study indicate that project-based learning analytics can serve as a diagnostic framework for examining the quality of biology teaching module development among prospective biology teachers. Although students from classes 5A and 5B demonstrated relatively strong and homogeneous overall achievement, with a total mean final score of 81.34 and a standard deviation of 2.23, these scores did not fully represent the conceptual quality of the teaching modules produced. If the evaluation were based only on final grades, the project-based learning process could be interpreted as generally successful. However, the analysis of project components and design-gap rubrics revealed that administrative completion did not necessarily correspond to strong instructional design quality. This result shows that learning analytics is useful not only for summarizing achievement, but also for locating hidden weaknesses in the design process. This finding supports the view that learning analytics should not be limited to reporting learning outcomes but should also function as a diagnostic instrument that connects process and outcome data to identify areas of instructional design requiring further improvement (Bauer et al., 2022; Zhong, 2017).

The most prominent finding in this study lies in the contrast between administrative completion and conceptual design quality. All administrative components, including project drafts and progress reports, reached 100.00% completion. In contrast, the conceptual components showed a gradual decline, from 82.50% in SW 1 to 63.30% in SW 4, and only 34.90% in the final teaching module. The sharp decline in the final module is important because this product required the integration of all previous project components. This pattern suggests that students were able to follow project procedures and submit required documents, but not all groups were able to integrate the module components into a coherent instructional design. Therefore, task completion should not be equated with meaningful learning or high-quality instructional design. Design quality requires evidence of knowledge transfer, metacognition, deep understanding, pedagogical justification, and the ability to apply knowledge in new educational contexts (Martínez-Pérez et al., 2022; Luo & Ye, 2021).

These findings reinforce the existence of an administrative-conceptual gap in the development of biology teaching modules. This gap emerges when students place greater emphasis on format completion, document submission, and procedural compliance than on pedagogical reasoning that connects learning objectives, biological content, learning activities, assessment, technology, and contextual issues. For example, several modules contained complete learning components, but the assessment tasks, digital media, and sustainability issues were not consistently linked to the stated learning objectives. In the relationship between educational policy and classroom practice, similar conditions may arise when administrative accountability is not accompanied by sufficient support for developing conceptual coherence in instructional design (Hilfert-Rüppell et al., 2021; Mangaroska et al., 2021). Thus, the main issue identified in this study is not low student participation, but the limited ability to construct meaningful conceptual relationships among the components of the module.

The largest design gap was found in sustainability integration, appearing in 76.90% of the modules, with an average rubric score of 2.39. This finding is particularly important because biology education has a strategic role in developing environmental literacy, climate literacy, and awareness of biodiversity. However, environmental issues, conservation, ecosystems, and the Sustainable Development Goals were not consistently positioned as the central orientation of instructional design. In several modules, sustainability appeared merely as an additional context or example rather than as an organizing principle for learning objectives, activities, assessment, and student action. This means that sustainability was present, but it was not always pedagogically functional. This condition is consistent with previous studies showing that sustainability integration in biology curricula often remains implicit and is not systematically connected to core biological concepts and learning activities (Isac et al., 2022; Hassan et al., 2020; Gopalakrishnan et al., 2019).

A substantial gap was also found in deep learning, with 69.20% of the modules showing weaknesses in designing activities that promote analysis, reflection, problem solving, and conceptual application. Some modules remained oriented toward completing learning tasks rather than fostering deep conceptual engagement. For instance, worksheets often guided students to complete answers, but did not always require them to analyze environmental evidence, compare alternatives, or justify biological explanations. In sustainability-oriented biology learning, students are expected not only to understand biological concepts but also to evaluate evidence, analyse system relationships, construct arguments, and connect scientific concepts with real-world problems. Deep understanding and knowledge transfer can develop when learning provides opportunities for inquiry, reflection, socioscientific reasoning, and the application of concepts in authentic contexts (Delen et al., 2024; Lasekan et al., 2020).

The gaps in assessment design and digital pedagogy further demonstrate that the quality of a teaching module should not be judged merely by the presence of its components, but by the functional alignment among those components. The results showed that 61.50% of the modules had gaps in assessment design and 53.80% had gaps in digital pedagogy. This indicates that assessment tools and digital media were present, but they were not always aligned with learning objectives, activities, worksheets, and sustainability competencies. In practical terms, some modules included digital media as presentation support, while the assessment remained focused mainly on factual recall or general task completion. Assessment in sustainability-oriented biology education should measure not only content mastery but also critical thinking, reflection, collaboration, decision making, and ecological action. Similarly, digital technology should not function merely as a visual supplement. It needs to be designed within the TPACK framework to support feedback, collaboration, inquiry, and authentic assessment (Baumgartner, 2022; Luo & Ye, 2021; Wu & Li, 2025; Zhong, 2017).

These findings have direct implications for the preparation of prospective biology teachers. Design guidance needs to be more explicit, structured, and gradual. Rubrics should be made more operational so that students can clearly understand the indicators of coherence among learning objectives, activities, assessment, technology, deep learning, and sustainability (Wu & Li, 2025; Hilfert-Rüppell et al., 2021). In addition, model modules, structured templates, collaborative planning, community-based projects, real-environment learning, and TPACK-based support may help students develop more coherent, meaningful, and contextual teaching modules (Kanandjebo, 2024; Blosser & Cavendish, 2023; Ortíz et al., 2019; Evans et al., 2016). A concrete pedagogical model may include staged module drafting, rubric-guided peer review, explicit sustainability mapping, digital-pedagogy planning, and formative lecturer feedback before final submission. Nevertheless, this study has several limitations. It was conducted in a single course context, analysed 13 group-based modules, and did not examine the effectiveness of the modules on senior high school students' sustainability literacy. Future research should therefore expand the research context, include reflective interviews with prospective teachers, strengthen rubric validation, and examine the implementation of the modules in actual biology classrooms.

CONCLUSION AND SUGGESTION

This study shows that project-based learning analytics can be used to examine the quality of teaching-module development among pre-service biology teachers beyond final grades and task-submission completeness. The students demonstrated relatively good and homogeneous overall performance, with a mean final score of 81.34. However, more detailed analysis of project components showed that this overall performance did not fully reflect the conceptual quality of teaching-module design. Administrative components reached full target achievement at 100.00%, whereas the final teaching module reached only 34.90% target achievement. This contrast indicates that administrative completion does not automatically lead to conceptually coherent instructional design. These findings confirm the existence of an administrative–conceptual gap in the development of biology teaching modules.

The most prominent gap occurred in sustainability integration at 76.90%, followed by deep learning at 69.20%, assessment design at 61.50%, digital pedagogy at 53.80%, and curriculum alignment at 46.20%. This pattern shows that pre-service biology teachers need not only the ability to prepare complete teaching-module documents but also the ability to coherently connect learning objectives, biology content, assessment, digital media, deep-learning activities, and sustainability issues. The main contribution of this study is therefore its diagnostic perspective: project-based learning analytics helps identify design weaknesses that remain hidden when evaluation relies only on scores or document completion. Suggestion. The practical implications of these findings include the need for more operational rubrics, formative feedback, module examples, and design scaffolding that help students integrate curriculum, assessment, technology, deep learning, and sustainability. Teacher education courses should guide students through staged module development, explicit sustainability mapping, rubric-based peer review, and feedback before final submission. Future research may extend this inquiry through content analysis of teaching modules, reflective interviews, more rigorous rubric validation, and implementation testing of the modules in relation to senior high school students' sustainability literacy.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, E.F. and R.R.M.; methodology, E.F.; validation, E.F. and R.R.M.; formal analysis, E.F.; investigation, E.F.; resources, E.F.; data curation, E.F.; writing—original draft preparation, E.F.; writing—review and editing, E.F. and R.R.M.; visualization, R.R.M.; supervision, E.F.; and project administration, E.F. All authors have read and agreed to the published version of the manuscript.

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DECLARATION OF GENERATIVE AI SOURCES

During the preparation of this manuscript, the author(s) used ChatGPT for language improvement, grammar checking, translation assistance, and structure refinement. All generated content was carefully reviewed, revised, and verified by the author(s), who take full responsibility for the final content of the manuscript.

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