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Designing Project-Based Learning Instruments Integrated with TPACK Framework to Enhance Students' HOTs

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Abstract

21st-century learning requires every student to have thinking skills, work habits, and character to achieve an independent and successful life. Learning in schools must develop students' thinking skills, including biology learning. The learning process in schools has undergone many changes during the COVID-19 pandemic. A study by the Ministry of Education, Research, and Technology (Kemendikbudristek) stated that the COVID-19 pandemic resulted in a significant decline in student literacy and numeracy and a learning loss. Learning in schools faces many challenges. Efforts and strategies are needed to empower thinking skills and learning recovery during the transition to the post-pandemic era in the Merdekabelajar program, including choosing appropriate learning strategies. Constructive and effective learning strategies. The Project-Based Learning (PjBL) model is the right learning model to implement by activating students through project assignments to achieve an in-depth understanding of essential materials and HOTS empowerment. The PjBL model is effective for catching up on learning so far, but tends only to activate high-achieving students. Students with low academic abilities, including low analysis, synthesis, and creation skills, cannot follow the learning process. The PjBL model needs to be integrated into an approach that considers pedagogical concepts, technology, and scientific content, namely the Technological Pedagogical and Content Knowledge (TPACK) approach.

Introduction

School learning must develop students' thinking skills and character, including in science learning (biology) (Anazifa & Djukri, 2017). Science education must equip students with deeper learning than just memorizing facts; students must apply their scientific knowledge in situations requiring problem-solving and decision-making (Miller & Krajcik, 2019). Current learning has undergone many changes. The empowerment of thinking skills is less than optimal, and there is a significant loss of literacy and numeracy learning. The research revealed that students' thinking skills and understanding of essential material were low (Fajari & Chumdari, 2021; Lestari et al., 2021; Yenti, 2020). Learning does not provide enough space for students to use experience in constructing their knowledge.

Biology learning should empower science attitudes and HOTS so that learning objectives are based on scientific developments (Setiawati & Corebima, 2019). In line with previous opinions, current learning must follow rapid technological developments, and the need for workers with technical knowledge and critical and creative thinking skills is increasing (I. A. C. Dewi et al., 2025). The world of work is increasingly dynamic following the times that demand creative things. Similar information was also obtained during teacher mentoring in the 2023 In-Service Teacher Professional Education, which reported that learning did not empower HOTS due to inappropriate learning tools.

This learning loss requires rapid recovery efforts. Efforts can be made by preparing learning devices that use appropriate learning approaches and models. Constructivist and contextual learning are effective alternatives for empowering HOTS and student characters, such as the TPACK approach and the PjBL learning model. The PjBL model activates students by giving project assignments, focusing on essential materials, in-depth learning for mastery of basic competencies and HOTS, and independence (Barak & Asad, 2012). Students' thinking skills will not develop independently in line with their age if done intentionally (Salmon & Barrera, 2021). The PjBL model has weaknesses, which tend to design projects that are less empowering HOTS and character, and only activate high academic students; students with low academic abilities cannot follow the learning. The PJBL model must be integrated with learning to empower low-achieving students' thinking skills and character.

The same thing was also reported (Ammade et al., 2020; Armiyati & Habib, 2022; Durdu & Dag, 2017) that the TPACK approach activates the construct capabilities of lower academic learners, which provides opportunities for high-level thinking, use of technology, and in-depth scientific understanding. Integrating the PjBL model syntax into the TPACK Approach is expected to overcome the shortcomings of PjBL, which will provide opportunities for learners with different academic abilities to develop at the individual and group levels to empower high-level thinking skills and student character. Based on this rationale, developing a learning tool based on the TPACK Integrated Project Approach in secondary schools, especially in biology learning, is necessary to empower high-level thinking skills and the character of the Pancasila Student Profile of learners with different academic abilities.

Method

The development of Project-Based Learning instruments integrated with the TPACK framework to enhance students' higher-order thinking and higher-order Thinking Skills (HOTs) refers to the Four-Dimensional (4-D) development model proposed by Thiagarajan et al. (1974). This model consists of four stages: the definition stage, design stage, development stage, and dissemination stage.

Define Stage

This stage aims to determine and define the learning requirements, starting with analyzing the objectives of the material limitations, including the main steps. Front-end analysis aims to determine the fundamental problems faced in biology learning. Student analysis is also carried out to determine students' academic abilities. Task analysis includes content structure analysis and procedural analysis. Concept analysis includes identifying the concepts learned and formulating learning objectives.

Design Stage

This stage aims to produce a design of learning strategies and tools. The design of learning tools consists of five steps, namely (a) selection of syllabus format and learning implementation plan, (b) initial design of syllabus preparation, learning implementation plan, (c) preparation of essay tests to measure metacognitive skills, critical and creative thinking, and retention (d) preparation of questionnaires to measure students' science attitudes (f) preparation of observation sheets for the implementation of learning syntax, rubrics for metacognitive skills, critical thinking, creative thinking and questionnaires for responses to learning strategies. The results of this stage are prototypes of learning tools that include a syllabus, RPP, LKPD, and evaluation tools.

Critical Thinking and Creative Thinking Skills Test

The test is constructed in essay format, following the taxonomy framework by Krathwohl and Anderson (2010). Before its administration, a comprehensive validation process is conducted, including content validity to ensure alignment with learning objectives, construct validity to confirm that the test measures the intended cognitive constructs, and empirical validity based on statistical analysis. In addition, the reliability of the test is established to ensure consistency and accuracy of the assessment results.

Critical and Creative Thinking Skills Rubric

As proposed (Reynders et al., 2020), a critical thinking skills rubric is employed to evaluate students' critical thinking and information processing abilities within undergraduate STEM classrooms and provide formative feedback that supports learning development. Meanwhile, the assessment of creative thinking skills is based on a rubric developed by (AS et al., 2021), which serves as a guideline for measuring students' capacity for innovation, originality, and problem-solving.

Pancasila Student Character Questionnaire

The Pancasila Student Character Questionnaire, developed by Satria et al., utilizes a modified Likert scale ranging from 1 to 4. This instrument is designed to measure students' character traits in alignment with Pancasila's values, providing quantitative data to support character education assessment.

Student Response Questionnaire on Learning Strategies

The Student Response Questionnaire on Learning Strategies captures students' perceptions and feedback regarding the instructional strategies implemented during the learning process. It evaluates the strategies' effectiveness and relevance from the learners' perspective.

Develop Stage

Producing revised learning devices based on input from experts, followed by a trial of the test instrument by students, which is then used as a basis for determining the validity of the items and the reliability of the test. This stage produces learning devices used in experimental research that have been validated.

Disseminate Stage (Modified to Experimental Research Stage)

This stage is a limited-scale trial stage on the devices that have been developed, including validated PJBL, TPACK, and PJBL-TPACK character devices. In addition to learning devices, the instruments developed consist of learning device validation sheets, teacher and student response questionnaires to learning devices, critical thinking skills tests, creative thinking skills tests, character questionnaires, and learning implementation observation sheets.

Results and Discussion

Define Stage

Curriculum Analysis

The Independent Curriculum develops competencies in attitudes, knowledge, and skills. So, learning targets include the development of the domains of attitudes, knowledge, and skills elaborated for each educational unit. Learning characteristics are adjusted to the Graduate Competency Standards (SKL) for the Senior High School (SMA) level and the characteristics of students' abilities and development levels. Assessments in the Independent Curriculum include assessments of spiritual attitudes, social attitudes, knowledge, and skills. Learning completion is determined by considering competency aspects, both in the form of tests and non-tests (projects).

Student Analysis

This analysis examined students' characteristics, including background knowledge (upper, middle, and lower academic ability) and cognitive development. Grade X Phase E students accepted at Parepare State High School are students who graduated in the 2024/2025 Academic Year.

Concept Analysis

Material analysis aims to identify, detail, and systematically organize the main concepts related to the subject matter in the Independent Curriculum. The concepts taught in the odd semester include descriptions of Learning Outcomes (CP), Learning Objective Flow (ATP), Teaching Modules, and LKS.

Task Analysis

This task analysis is carried out after knowing the concept to be taught so that the tasks that must be completed during the learning process can be known, and it can also make it easier for teachers to formulate specific goals to be achieved. The tasks that students in the learning process will carry out are (1) reading books/student teaching materials and discussing with group members to obtain/collect information in completing/answering questions in the LKS and student books/teaching materials, (2) completing projects based on the TPACK approach on the material Viruses and Biodiversity.

Learning Objective Specification Analysis

Learning objective analysis is intended to determine the relevant behaviour and knowledge students need to achieve competencies or learning objectives. It is compiled based on Learning Outcomes, as stated in the Independent Curriculum structure.

Design Stage

This stage involves designing learning devices through the PjBL-TPACK strategy to empower students' high-level thinking skills (critical and creative thinking). Learning Objective Flow, teaching modules, and student activity sheets are developed. The three learning devices are explained below.

Integrated PjBL Syntax Products TPACK Approach

This study developed the combination of PjBL syntax and the TPACK approach, which is hereinafter referred to as the PjBL-TPACK strategy. The syntax of the TPACK-integrated PjBL Learning Strategy consists of the stages of determining basic questions and implementing technology, designing project planning, making schedules, working in groups, monitoring project progress, assessing results, and evaluating experiences.

The integration of the PjBL learning model in TPACK into the PjBL-TPACK model is based on the suitability of the syntax that can be integrated. The six stages in the PjBL strategy syntax direct students to construct new knowledge based on previously owned knowledge individually. The TPACK approach primarily directs the use of the PjBL model to develop concepts/content through the application and use of technology. This combination of strategies is carried out to maximize the potential of each PjBL and TPACK model. The six-stage activities in the PjBL model are gradual activities to train and develop students' critical and creative thinking skills. The PjBL model is a strategy that helps students focus on organizing information in their minds and making it meaningful. According to Demirdöğen et al. (2016), understanding is a prerequisite for higher levels of knowledge. The six-stage integration of the PJBL model into the technological, pedagogical, and content implementation approaches trains the thinking process.

Development Stage (Develop)

Description of Learning Device Development Results

This stage aims to produce learning devices that are suitable for use in classroom learning activities. The initial design of the learning device (draft I) is given to the expert/validator to be assessed, which is then revised by considering the suggestions/input from the expert/validator.

Learning Device Validity Data Analysis

Learning Objective Flow (ATP)/Syllabus Validation Results

The Learning Objective Flow is a one-semester learning program design that contains components consisting of identity (name of compiler, institution/phase, learning achievement), elements, CP, keywords, Learning Objectives, and ATP. The development of CP into ATP and teaching modules is the development of devices sequentially, including (1) determining identity, (2) formulating learning objectives, (3) formulating indicators, (4) identifying primary material/learning materials, (5) determining assessments, (6) determining time allocation, (7) determining learning resources. The aspects considered in validating teaching modules are format, content/material, language, time, learning methods/activities, and assessment. The aspects assessed are: 1). format, 2). content/material, 3). Language, 4). ATP Validity Data Analysis is shown in Table 1.

Table 1. ATP Validity Data Analysis

Validation Aspects	Result (x)	Indicator	Category/Status
Syllabus Format	3.70	$3.5 \leq x \leq 4.0$	Very valid
Content/Material	3.80	$3.5 \leq x \leq 4.0$	Very valid
Language	3.50	$2.5 \leq x < 3.5$	Very Valid
Average	3.65	$3.5 \leq x \leq 4.0$	Very valid

Based on the validity criteria, this value is included in the “very valid” category ($3.5 \leq x \leq 4.0$) because all aspects have met the validity criteria, so this syllabus is declared suitable for use in research. Although overall aspects have met the validity criteria, several expert suggestions need to be considered for the perfection of ATP.

Teaching Module Validation Results

The teaching module is a planning program prepared as a guideline for implementing learning for each learning process activity. The components of the teaching module include learning objectives, learning materials, (1) determining identity, (2) formulating learning objectives, (3) formulating indicators, (4) identifying primary material/learning materials, (5) determining assessments, (6) determining time allocation, (7) determining learning resources.

The teaching module consists of 3 types: the PjBL teaching module, the TPACK teaching module, and the PjBL-TPACK teaching module. All three were developed to have differences in the learning activities experienced by students, according to each syntax/step of the related strategy. The teaching module was developed based on the Independent Curriculum, which uses elements of Biology Understanding and 6 M process skills (Observing, Asking, Planning and Collecting Data, Processing and Analyzing Data and information, Evaluating and Reflecting, and Communicating). Analysis of the RPP Validity Data is shown in Table 2.

Table 2. Analysis of Teaching Module Validity Data

Validation Aspects	Result (x)	Indicator	Category/Status
Teaching Module Format	3.8	$3.5 \leq x \leq 4.0$	Very valid
Content/Material	3.8	$3.5 \leq x \leq 4.0$	Very valid
Language	3.5	$2.5 \leq x < 3.5$	Very Valid
Time	3.4	$2.5 \leq x < 3.5$	Valid
Learning Methods/Activities	3.8	$3.5 \leq x \leq 4.0$	Very valid
Evaluation	3.7	$3.5 \leq x \leq 4.0$	Very valid
Average	3.7	$3.5 \leq x \leq 4.0$	Very valid

Based on the validity criteria, this value is included in the “very valid” category ($3.5 \leq x \leq 4.0$) because all aspects have met the validity criteria, and this teaching module is declared suitable for use in research. Although overall aspects have met the validity criteria, several expert suggestions need to be considered for the perfection of the teaching module. According to (N. R. Dewi et al., 2022), the teaching module that developed the TPACK Project-Based Scaffolding Model design significantly increased students’ (prospective teachers) ability to design learning compared to the control group. The same thing was also reported by (Antonio, 2025) that the effectiveness of this strategy was seen in developing TPACK in various dimensions and increasing knowledge of technology, pedagogy, and content in students.

Student Activity Sheet (LKS) Validation Results

Student activity sheets (LKS) are activity sheets that contain materials or problems that students work on or discuss during the learning process. In addition, LKS contains steps of activities carried out by students during the learning process. LKS are developed based on the syntax of the applied learning strategy. The LKS developed consists of three types: LKS PjBL, LKS TPACK, and LKS PjBL-TPACK. The three types of LKS contain the same learning material.

There are 4 PjBL LKS developed. The LKS is intended for all students. There are 4 TPS LKS developed. The LKS is intended for all group members. There are 4 PjBL-TPS LKS developed. The LKS is intended for all group members. The aspects considered in validating Student Activity Sheets (LKS) generally are the LKS format, content, and language. Each aspect consists of several criteria that are assessed. LKS Validity Data Analysis is shown in Table 3.

Table 3. Analysis of LKS Validity Data

Validation Aspects	Result (x)	Indicator	Category/Status
LKS Format	3.8	$3.5 \leq x \leq 4.0$	Very valid
Content/Material	3.7	$3.5 \leq x \leq 4.0$	Very valid
Language	3.6	$2.5 \leq x < 3.5$	Very Valid
Average	3.7	$3.5 \leq x \leq 4.0$	Very valid

Based on the validity criteria, this value is included in the “very valid” category (3.5 ≤ x ≤ 4.0) because all aspects have met the validity criteria, so this LKS is declared suitable for use in research.

Student Teaching Material Validation Results

The aspects considered in the validation of student books in general are the format of the student book/teaching material, the content/material of the book, and the language. Each aspect consists of several criteria that are assessed.

The data analysis of the validity of student teaching materials is shown in Table 4.

Table 4. Analysis of Student Teaching Material Validity Data

Validation Aspects	Result (x)	Indicator	Category/Status
Teaching Material Format	3.7	3.5 ≤ x ≤ 4.0	Very valid
Content/Material	3.7	3.5 ≤ x ≤ 4.0	Very valid
Language	3.6	2.5 ≤ x < 3.5	Very Valid
Average	3.67	3.5 ≤ x ≤ 4.0	Very valid

Based on the validity criteria, this value is included in the “very valid” category (3.5 ≤ x ≤ 4.0) because all aspects have met the validity criteria, so this teaching material is declared suitable for use in research.

Instrument Validation Results

The instrument consists of a critical and creative thinking skills test integrated into the learning outcome test and a critical and creative thinking character inventory. The validity of the critical and creative thinking skills test integrated into the learning outcome test is included in the valid (0.63) and reliable (0.92) categories, and that of the critical and creative thinking character inventory is in the valid (0.65) and reliable (0.93) categories. Based on the validation results and suggestions/input from experts, improvements/revisions were made to the learning device (draft I), resulting in a revised learning device (draft II). Furthermore, the revised learning device (draft II) was tested in classroom learning activities.

Learning Management

Learning management data was obtained through observations made by two observers using a learning management observation sheet. Observations of learning management were carried out three times, namely at each meeting. The aspects of observation contained in the observation sheet include (1) initial activities, (2) core activities, (3) final activities, and (4) classroom learning atmosphere. The teachers’ analysis of learning management data showed that the teacher’s ability to manage learning was adequate because all aspects of teacher observation in learning management had met the criteria. The teacher’s ability to manage learning can be stated as adequate if the minimum KG value is in the high category (Sims et al., 2021). The learning devices developed after trials have met the criteria for effectiveness. Based on the analysis of the learning device trials and suggestions/input from observers, revisions/improvements were made to the learning devices (draft II). The results of the revision/improvement of the draft II learning devices produced draft III learning devices.

Distribution Stage

The distribution of learning devices was limited through socialization to Biology subject teachers at Parepare State Senior High School through MGMP activities. The socialization was conducted in the Science laboratory of Parepare State Senior High School 1 and was attended by 15 biology subject teachers. In this activity, the researcher explained how to use the devices related to the learning steps in the teaching module according to the characteristics of learning using the PjBL, TPACK, and PjBL-TPACK strategies integrated with a scientific approach. Furthermore, biology subject teachers who had participated in the socialization were asked to write responses/feedback and provide suggestions regarding the learning devices that had been developed. Based on suggestions and responses from subject teachers, it became the basis for improving/revising the draft III learning device. The revision results of draft III produced the Draft Final learning device, which was tested on a limited scale at Parepare State Senior High School 2 using 1 one Class XI MIPA1 Odd semester of the 2024/2025 academic year. The results of the revision of draft III, which was tested on a limited scale, showed that HOTS-based learning was important for training students' thinking skills. According to Öztürk (2023), intensive learning in thinking has a good influence on students' academic progress. Therefore, developing higher-order thinking Skills in learning materials is a crucial aspect of education.

Conclusion

This study confirms that developing instructional tools integrating Project-Based Learning (PjBL) and the Technological Pedagogical and Content Knowledge (TPACK) framework is highly valid and appropriate for classroom implementation. The integration effectively addresses the limitations of the traditional PjBL model, which tends to benefit only high-achieving students, by offering inclusive opportunities for students across various academic levels to engage and develop. The validated instructional components—including the syllabus, teaching modules, student worksheets, and learning materials—met the high-quality and educational soundness criteria. These findings highlight the pedagogical potential of combining technological, pedagogical, and content-based approaches to foster higher-order thinking skills (HOTS), particularly critical and creative thinking, while simultaneously cultivating students' character in alignment with the Pancasila Student Profile. Although this research was limited to the design and small-scale trial phases, the outcomes contribute meaningfully to the discourse on 21st-century learning innovation. They suggest that the PjBL-TPACK model can be an effective instructional strategy for promoting learner autonomy, collaboration, and inclusive technological literacy in the post-pandemic educational landscape.

Recommendations

Given the promising results of this study, it is recommended that the PjBL-TPACK integrated instructional model be implemented on a broader scale, particularly in secondary school biology curricula. This broader application would comprehensively evaluate its effectiveness in enhancing students' higher-order thinking skills across diverse learning environments. Educators should be provided with systematic professional development programs to design and implement instruction grounded in the TPACK framework. Such training would support integrating technology, pedagogy, and content knowledge in classroom practice. Additionally, educational stakeholders and policymakers should offer institutional support, including resources and regulatory frameworks, to ensure the sustainable adoption of innovative instructional strategies. Future research should further investigate the long-term impact of the PjBL-TPACK model on student learning outcomes and character development. Emphasis should also be placed on assessing students' engagement and adaptability in technology-rich learning contexts. Ultimately, the PjBL-TPACK model represents a transformative approach for equipping students with the critical competencies necessary to thrive in a complex and rapidly evolving global society.

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