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Hybrid-PjBL Model Integrating Local Wisdom, Scientific Curiosity, and Metacognitive Awareness: Content and Construct Validity

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Abstrac

Procedural knowledge is an essential component of 21st-century science learning because it enables students to select, apply, and evaluate strategies for solving scientific problems. Project-Based Learning (PjBL) is widely recognized as a student-centered model for developing problem-solving, collaboration, and higher-order thinking skills; however, its implementation still requires stronger support for students' learning regulation, motivation, and contextual scientific inquiry. This study examined the content validity, expert-based construct coherence, and reliability of a Hybrid Project-Based Learning (Hybrid-PjBL) model integrating local wisdom, scientific curiosity, and metacognitive awareness to support prospective science teachers' procedural knowledge. This study represents the validation stage of a development research project. The developed model and its supporting tools, including semester learning plans (RPS), learning scenarios, modules, student worksheets (LKPD), and assessment instruments, were validated through a focus group discussion involving seven validators: four experts and three practitioners. Data were collected using validation sheets and analyzed descriptively using validity coefficients and reliability estimates. The results showed that the Hybrid-PjBL model was valid and reliable ($r\alpha = 0.76$; $\alpha = 0.86$). The supporting tools were also categorized as valid and reliable, including RPS ($r\alpha = 0.85$; $\alpha = 0.92$), learning scenarios ($r\alpha = 0.81$; $\alpha = 0.89$), modules ($r\alpha = 0.78$; $\alpha = 0.88$), LKPD ($r\alpha = 0.95$; $\alpha = 0.97$), and assessment instruments ($r\alpha = 0.88$; $\alpha = 0.93$). These findings indicate that the developed model and tools are appropriate for further practicality and effectiveness testing in real classroom settings.

Keywords: Hybrid-PjBL; Local Wisdom; Scientific Curiosity; Metacognitive Awareness; Procedural Knowledge

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INTRODUCTION

The utilization of online learning has experienced a surge in tandem with the prevalence of the Covid-19 pandemic within Indonesia over the past three years. Regrettably, online learning grapples with certain challenges, including inadequate digital literacy (Egorov et al., 2021), instances of student assignment plagiarism and tardiness (Aikina & Bolsunovskaya, 2020). These issues are recurrent in online learning, often resulting in a decline in students' affective aspects, such as motivation (Chaeruman, 2018), their sense of responsibility for independent study (Pratama et al., 2019), and suboptimal learning design (Sole & Anggraeni, 2018). Surprisingly, the outcomes of this study do not align with the anticipation that online learning should deliver commensurate benefits and motivation to students as traditional face-to-face learning, particularly in terms of learning processes and outcomes (Lynch, 2020).

These challenges indicate that online learning should not merely transfer face-to-face instruction into digital platforms. Instead, it requires a learning model that combines flexible online activities with meaningful face-to-face interaction, structured inquiry, collaboration, and reflection. In science teacher education, this need is particularly important because prospective science teachers must develop procedural knowledge, namely knowledge of how to plan, select, implement, monitor, and evaluate scientific procedures and problem-solving strategies.

Project-Based Learning (PjBL) is a student-centered model that adheres to scientific principles, particularly the scientific process, such as biology (Crippen et al., 2016). It is designed to cultivate students' active collaboration and communication skills (Kokotsaki et al., 2016), enhance problem-solving abilities and critical thinking (Husamah, 2015; Jerome et al., 2017). Another study discovered that PjBL, centered on authentic problem-solving, significantly enhanced students' cognitive skills (Fini et al., 2018). The PjBL model necessitates students' engagement in tackling intricate, authentic problems (Masino & Niño-Zarazúa, 2016), necessitating comprehensive knowledge and strategic planning throughout the learning process (Muhali et al., 2019).

Notably, inadequate comprehension of concepts can impede the PjBL model, leading to suboptimal problem-solving strategy formulation, which is closely related to procedural knowledge. Interestingly, the PjBL model was found to not only enhance learning experiences and student collaboration but also increased learning satisfaction, although it did not necessarily lead to improved learning outcomes (Rambocas & Sastry, 2017; Noguera et al., 2018). Project-oriented learning, focusing on authentic problems, did not consistently impact metacognition awareness, particularly debugging (Tosun & Senocak, 2013), student motivation (Rahardjanto et al., 2019), and was not universally suitable for all subjects (Grossman et al., 2019). Some research advises instructors to pay attention to students' understanding of learning objectives, accessibility of materials for problem-solving projects, emphasize the enhancement of scientific literacy (Li, 2021), utilize performance assessment with portfolio (Guo et al., 2020), and integrate PjBL within modern hybrid learning approaches (Efstratia, 2014).

Previous studies suggest that PjBL can become more meaningful when it is connected to students’ sociocultural environments and authentic local problems. Local wisdom and ethnoscience-based learning have been reported to support culturally relevant science learning, critical thinking, scientific literacy, and local cultural concern (Hikmawati et al., 2021; Suastra et al., 2021; Sumarwati et al., 2020). Recent evidence also shows that local wisdom integration has become an important trend in education because it can support culture-based learning and educational relevance (Arjaya et al., 2024). In this context, local wisdom can function as an authentic problem source for project activities, while scientific curiosity encourages students to ask questions, explore phenomena, collect evidence, and construct scientific explanations.

The integration of metacognitive awareness is also essential because PjBL requires students to regulate their own learning. Metacognitive awareness supports students in planning project strategies, monitoring progress, evaluating evidence, managing information, and revising problem-solving procedures (Asy’ari et al., 2019; Thomas, 2012; Zohar & Barzilai, 2013). Therefore, metacognitive awareness can strengthen the procedural dimension of PjBL by helping students understand not only what they learn but also how they solve scientific problems.

This study addresses the gaps and recommendations from prior research. The PjBL model in this study is oriented towards students and accentuates active involvement in communication and collaboration during learning. It integrates metacognitive awareness (Asy’ari et al., 2019), scientific curiosity (Hunaepi et al., 2021), and is founded on hybrid learning principles (Hidayah et al., 2021) to mitigate the limitations of the PjBL model, primarily focusing on students' procedural knowledge, identified as a vital element in 21st-century thinking skills (Asy’ari et al., 2019). Consequently, this research is of great significance, particularly considering the demands of online learning amidst the Covid-

19 pandemic and the suggestions from previous studies. Additionally, it aligns with national research priorities in the realm of social humanities, concentrating on character development and competitiveness through the infusion of local wisdom in learning, which is epitomized in scientific curiosity attributions within the Hybrid-PjBL model. The ultimate goal is to foster educational innovation and enhance multimedia literacy in learning.

Although previous studies have reported the benefits of PjBL, hybrid learning, metacognitive awareness, local wisdom, and scientific curiosity, fewer studies have systematically validated a Hybrid-PjBL model that integrates these components into one coherent instructional framework for prospective science teachers. Therefore, an initial validation study is needed to examine whether the model and its supporting tools demonstrate content validity, expert-based construct coherence, and reliability before they are implemented in classroom-based practicality and effectiveness testing.

This study aims to evaluate the content validity, expert-based construct coherence, and reliability of a Hybrid-PjBL model integrating metacognitive awareness and local wisdom scientific curiosity, together with its supporting learning tools. In this study, construct validity is interpreted as expert-based appraisal of the theoretical coherence and internal consistency among the model rationale, syntax, social system, reaction principles, support system, instructional impact, and expected accompanying impact.

METODE

Research Design

This study is a quantitative study that aims to evaluate the feasibility (Malhotra, 2011) of attributions of metacognitive awareness and local wisdom-scientific curiosity that are integrated in the learning step of the Hybrid-PjBL model. In addition, learning tools and assessment instruments will also be produced in this study.

This study represents the validation stage of a development research project. The main purpose of this stage was to examine the content validity, expert-based construct coherence, and reliability of the Hybrid-PjBL model and its supporting learning tools before conducting practicality and effectiveness testing in real classroom settings. Therefore, this study does not claim to test the empirical effectiveness of the model in improving students' procedural knowledge.

Product Description

The products validated in this study consisted of: (1) the Hybrid-PjBL model integrating metacognitive awareness and local wisdom–scientific curiosity; (2) semester learning plans (RPS); (3) learning scenarios; (4) learning modules; (5) student worksheets (LKPD); and (6) assessment instruments for procedural knowledge.

The Hybrid-PjBL model was designed as a project-based instructional model that combines online and face-to-face learning activities. The model positions local wisdom as an authentic source of scientific problems, scientific curiosity as a driver of questioning and investigation, and metacognitive awareness as a mechanism for planning, monitoring, evaluating, and revising students' learning strategies.

Operational Definitions

Hybrid-PjBL refers to a project-based learning model implemented through a combination of online and face-to-face activities to facilitate authentic problem investigation, collaboration, product development, presentation, and reflection.

Metacognitive awareness refers to students' awareness and regulation of their learning processes, including planning, monitoring, evaluating, information management, and debugging during project-based scientific problem solving.

Local wisdom–scientific curiosity refers to the integration of local cultural, ecological, or community-based phenomena into science learning activities to stimulate students' curiosity, questioning, exploration, and scientific explanation.

Procedural knowledge refers to knowledge about how to select, apply, justify, and evaluate procedures or strategies for solving scientific problems and completing project-based tasks. Content validity refers to the relevance and appropriateness of the model and learning tools in relation to learning objectives, scientific content, procedural knowledge indicators, and instructional needs. Construct validity in this study refers to expert-based appraisal of the theoretical coherence and internal consistency of the model components. It does not refer to empirical construct validation using factor analysis or classroom outcome testing.

Validators

The Hybrid-PjBL model integrated with Metacognition Awareness and Local Wisdom-Scientific Curiosity along with tools and instruments were validated in terms of content and constructs in a focus group discussion (FGD) forum which was attended by four competent experts with a minimum doctoral qualification, and practitioners consisting of three practitioners.

The validation process involved seven validators consisting of four expert validators and three practitioner validators. Expert validators were selected based on their doctoral qualification and expertise in science education, learning model development, educational evaluation, or instructional design. Practitioner validators were selected based on their experience in implementing science learning or project-based learning in educational contexts.

Validation Procedure

The validation procedure was conducted through the following stages. First, the researchers developed the initial prototype of the Hybrid-PjBL model and its supporting tools based on theoretical analysis, previous research, and instructional needs. Second, validation sheets were prepared to assess content relevance and construct coherence. Third, validators independently reviewed the model and learning tools using a four-point scale. Fourth, an FGD was conducted to discuss the validation results, qualitative suggestions, and necessary revisions. Fifth, the validation scores were analyzed descriptively, and reliability coefficients were calculated. Sixth, the model and learning tools were revised based on validator scores and qualitative feedback.

The content validity aspects included the relevance of learning objectives, suitability of learning materials, alignment with procedural knowledge indicators, clarity of learning activities, appropriateness of assessment indicators, and readability of learning tools. The expert-based construct coherence aspects included the consistency among theoretical rationale, model syntax, social system, reaction principles, support system, instructional impact, and expected accompanying impact.

Instruments and Data Analysis

The model validation instruments along with supporting devices were validated by experts before being used to assess the quality of the model and the devices according to the following validity formula, r = [(Average Square people - Average Square residual)/(Average Square people + (k-1) Average Square residual)] and Cronbach's alpha = k r / [1+ (k-1) r]. The criteria of the model validity and reliability instruments are shown in Table 1.

The validation sheets were used to obtain quantitative scores and qualitative comments from validators. A four-point scale was applied, consisting of: "much less valid

= 1," "less valid = 2," "valid = 3," and "very valid = 4." The average validation score was used to determine the category of product validity. The interrater correlation coefficient was used to indicate the consistency of validator judgments, while Cronbach's alpha was used to estimate the reliability of the validation results. Percentage agreement was used as an additional reference for determining the consistency of validator judgments.

Table 1. Validity and Reliability Criteria of the Model

Check	Scale Statistics	Category
Validity	Single measures interrater correlation coefficient, ICC ($r\alpha$)	
	$r\alpha \leq$ r table	Invalid
	$r\alpha >$ r table	Valid
Reliability	Cronbach's alpha / average measures interrater correlation coefficient-ICC (α)	
	$\alpha < .60$	Unreliable
	$.60 \leq \alpha \leq 1.00$	Reliable

The learning model underwent validation by experts and practitioners with expertise in the field of education. Feedback from these validators served as the basis for refining the model's structure until a valid syntax was achieved. Evaluation of the Hybrid-PjBL model and the learning tools was executed using a four-point scale, comprising the following ratings: "much less valid = 1," "less valid = 2," "valid = 3," and "very valid = 4." Expert assessments of the product development resulted in qualitative data, categorized on a four-point scale as presented in Table 2.

Table 2. Validity Criteria of Model and Learning Devices Based on Average Validator Values

Score Range	Criteria
> 3.60	Very valid
2.80 – 3.60	Valid
1.90 – 2.70	Less valid
1.00 – 1.80	Much less valid

The mean values denoting the validity and reliability of both the models and the supporting learning tools are established based on the judgments of the validators. The reliability of the learning tools is computed using Emmer and Millett's percentage agreement formula (Borich, 1994). An instrument is deemed reliable if it garners a percentage agreement of ≥ 75% or achieves an average score of 75% from the validator team within the valid category. To avoid overstatement, the statistical results in this study are interpreted as evidence of expert agreement and reliability during the initial validation stage. They do not represent classroom-based evidence of model effectiveness.

RESULTS AND DISCUSSION

Theoretical Foundation of the Hybrid-PjBL Model

Hybrid-PjBL is an inquiry-based collaborative learning model that emphasizes students' ability to integrate, apply, and construct knowledge in solving authentic and complex problems through both online and face-to-face learning activities (Guo et al., 2020; Ratumanan & Laurens, 2011). The components of metacognitive awareness and local wisdom–scientific curiosity are systematically integrated into each phase of the Hybrid-PjBL model to address the limitations identified in previous Project-Based Learning (PjBL) studies. Metacognitive awareness, particularly cognition regulation, is considered essential in controlling knowledge construction and attitudes toward science and technology (Lavi et al., 2021). Therefore, it is highly relevant for supporting students in constructing declarative and procedural knowledge while simultaneously enhancing learning motivation (Markula & Aksela, 2022), which has often been identified as a weakness of conventional PjBL implementation.

Metacognition is generally defined as “thinking about thinking” and consists of two major components, namely metacognitive knowledge and metacognitive awareness (Thomas, 2012; Zohar & Barzilai, 2013). This study specifically focused on metacognitive awareness integrated into the learning stages of Hybrid Project-Based Learning and its supporting tools within online and face-to-face classroom practices. Metacognitive awareness is associated with students’ abilities to regulate learning processes through activities such as planning, monitoring, evaluating, information management, and debugging (Asy’ari et al., 2019; Zohar & Barzilai, 2013). Students with high metacognitive awareness tend to possess stronger self-regulated learning abilities and a better understanding of how to organize their thinking processes effectively (Holzberger et al., 2021).

In addition, the Hybrid-PjBL model integrates local wisdom–scientific curiosity attributes to encourage more authentic problem formulation during learning activities. Scientific curiosity reflects an individual’s enthusiasm for observing, investigating, listening, exploring, and seeking information (Lamnina & Chase, 2019). Curiosity is considered important because it contributes to the retention of information in long-term memory and promotes meaningful learning experiences (Lamnina & Chase, 2019). Consistent with previous findings, scientific curiosity positively contributes to students’ attention, concentration, exploration behavior, questioning skills, conceptual understanding, and learning skills (Hunaepi et al., 2021; Mouromadhoni et al., 2019). Therefore, integrating scientific curiosity with local wisdom contexts can facilitate more contextualized and meaningful science learning experiences.

Recent studies on local wisdom, ethnoscience, and indigenous knowledge-based science learning strengthen the rationale for integrating local contexts into science instruction. Ethnoscience-based models have been reported to support critical thinking and local cultural concern (Hikmawati et al., 2021), while indigenous science-based instructional models can support local wisdom-based character development and higher-order thinking skills (Suastra et al., 2021). Traditional ecological knowledge can also be integrated into learning through contextual and activity-based strategies (Sumarwati et al., 2020). In higher education, a digital learning platform blending ethnoscience and inquiry has been shown to empower future science educators’ critical thinking (Prayogi et al., 2023). These findings support the theoretical basis of the Hybrid-PjBL model because the model combines authentic local contexts, inquiry-based investigation, digital learning, project work, and metacognitive regulation.

In the developed model, PjBL functions as the main instructional structure, hybrid learning functions as the delivery mode, local wisdom functions as the source of authentic scientific problems, scientific curiosity functions as the motivational and inquiry trigger, and metacognitive awareness functions as the self-regulatory mechanism. These components are expected to support procedural knowledge because students are required to identify problems, plan strategies, select procedures, collect and analyze evidence, evaluate project progress, and justify their scientific decisions.

In simple terms, the implementation framework of the Hybrid-PjBL model integrated with Metacognition Awareness and Local Wisdom-Scientific Curiosity is presented in Figure 1.

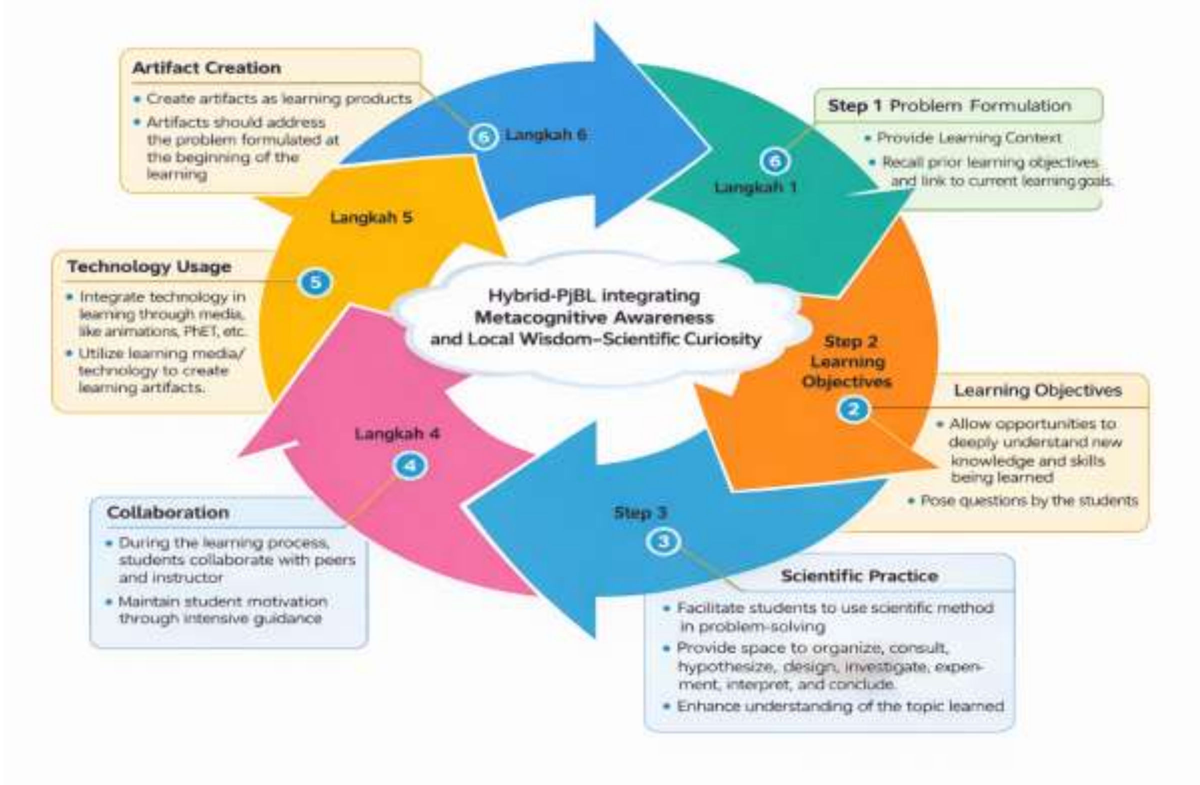

Figure 1. Learning Steps for the Integrated Hybrid-PjBL Model Awareness of Metacognition and Local Wisdom- Scientific Curiosity

Validation Results of the Hybrid-PjBL Model and Supporting Tools

The Hybrid-PjBL model integrated with Metacognitive Awareness and Local Wisdom–Scientific Curiosity, together with its supporting learning tools, was validated through Focus Group Discussion (FGD) activities involving seven validators consisting of four expert validators and three practitioner validators. The validity assessment was based on content validity and construct validity principles as proposed by Nieveen (1999). In this study, construct validity was interpreted as expert-based construct coherence, namely the theoretical consistency among the model rationale, syntax, social system, reaction principles, support system, instructional impact, and expected accompanying impact. The results of the model and learning tools validation are presented in Table 3.

Table 3. Validity of the Hybrid-PjBL Model Integrated with Metacognition Awareness and Local Wisdom–Scientific Curiosity, Including Supporting Tools

Item	rα	Category	α	Reliability
Model	0.76	Valid	0.86	Reliable
RPS	0.85	Valid	0.92	Reliable
Scenario	0.81	Valid	0.89	Reliable
Module	0.78	Valid	0.88	Reliable
LKPD	0.95	Valid	0.97	Reliable
Instrument	0.88	Valid	0.93	Reliable

The validation results indicate that the Hybrid-PjBL learning model achieved valid and reliable criteria, as evidenced by a validity score of rα = 0.76 and reliability coefficient of α = 0.86. These findings indicate that the validators showed consistent agreement regarding the relevance and coherence of the model components. The score suggests that the model has acceptable initial validity as an instructional framework, particularly in terms of its rationale, syntax, integration of metacognitive awareness, integration of local wisdom–scientific curiosity, and alignment with procedural knowledge indicators.

Furthermore, the developed learning model demonstrated strong consistency across its components, including theoretical rationale, learning objectives, instructional impacts, learning environment, social systems, reaction principles, and support systems. Fundamentally, the learning process within Hybrid-PjBL is grounded in scientific principles emphasizing observation and investigation of real-world phenomena closely related to students' environments (Eggen & Kauchak, 2012). This orientation is reflected in the reaction principles embedded within the model syntax, particularly in activities promoting inquiry, collaboration, and contextual problem solving.

The validation score of the model also indicates that the expert and practitioner validators considered the integration of hybrid learning, project-based learning, metacognitive regulation, local wisdom, and scientific curiosity to be theoretically coherent. This finding directly responds to the research objective, namely to examine whether the developed model is sufficiently valid and reliable for further implementation testing. However, the present result should be interpreted as initial validation evidence rather than empirical evidence of learning effectiveness.

The development of the Hybrid-PjBL model also corresponds to current educational demands emphasizing 21st-century competencies. The National Research Council highlighted the importance of fostering skills such as adaptability, communication, problem-solving, self-management, and systems thinking in science education (National Research Council, 2012). Similarly, local wisdom-based science learning has been positioned as a relevant approach for connecting science concepts with students' cultural and ecological contexts, while supporting critical thinking, communication, and scientific literacy (Arjaya et al., 2024; Hikmawati et al., 2021; Suastra et al., 2021). In this regard, the Hybrid-PjBL model integrated with Metacognitive Awareness and Local Wisdom–Scientific Curiosity accommodates these competencies through inquiry-based and collaborative learning experiences.

Validation Results of Supporting Learning Tools

The supporting learning tools also demonstrated high levels of validity and reliability, including semester learning plans (RPS) ($r\alpha$ = 0.85; α = 0.92), learning scenarios ($r\alpha$ = 0.81; α = 0.89), modules ($r\alpha$ = 0.78; α = 0.88), student worksheets (LKPD) ($r\alpha$ = 0.95; α = 0.97), and assessment instruments ($r\alpha$ = 0.88; α = 0.93). These findings suggest that the supporting tools are appropriate for facilitating inquiry-oriented learning processes within Hybrid-PjBL implementation.

The LKPD obtained the highest validity and reliability scores among the supporting tools. This result indicates that the student worksheets were considered highly aligned with the model syntax, project activities, inquiry processes, and procedural knowledge indicators. The LKPD plays an important role in guiding students to identify local phenomena, formulate scientific questions, plan investigations, document evidence, reflect on their strategies, and present project outcomes. Therefore, the strong validation result for the LKPD supports the feasibility of implementing the model in structured hybrid learning activities.

The RPS and learning scenarios were also categorized as valid and reliable, indicating that the learning objectives, learning stages, time allocation, instructional strategies, and assessment plans were considered consistent with the Hybrid-PjBL framework. The module and assessment instruments also met valid and reliable criteria, suggesting that the learning content and procedural knowledge indicators were sufficiently aligned with the expected instructional outcomes.

Interpretation of Content Validity and Expert-Based Construct Coherence

The inquiry-oriented characteristics of the model are particularly important because inquiry learning enables students to formulate scientific questions, develop hypotheses, analyze evidence, and construct scientific understanding independently (Eggen & Kauchak, 2012). Inquiry-based learning has also been shown to improve metacognitive awareness, critical thinking, and self-regulated learning abilities (Asy'ari et al., 2019). Consequently, integrating inquiry principles, metacognitive awareness, and scientific curiosity into Hybrid-PjBL can potentially strengthen students' procedural knowledge and higher-order thinking skills in science learning contexts.

From a content validity perspective, the model and learning tools were judged to be relevant to the needs of prospective science teachers because they emphasize authentic scientific problem solving, project planning, procedural decision-making, collaboration, and reflection. These components are consistent with the concept of procedural knowledge, which requires learners to understand how to apply strategies and procedures in specific problem contexts.

From an expert-based construct coherence perspective, the validation results suggest that the model components are internally consistent. The model rationale explains the need for hybrid, project-based, metacognitive, and local wisdom-oriented learning. The syntax translates this rationale into learning stages. The social system supports collaboration and communication. The reaction principles guide lecturers in facilitating inquiry and reflection. The support system provides learning tools and assessment instruments. The instructional impact is directed toward procedural knowledge, while the accompanying impact includes scientific curiosity, collaboration, communication, and appreciation of local wisdom.

Qualitative feedback from validators was used to refine the model syntax, clarify the role of local wisdom in problem formulation, strengthen metacognitive prompts in each project phase, and align the learning tools with procedural knowledge indicators. These revisions improved the clarity and consistency of the model before it proceeds to practicality and effectiveness testing.

Limitations of the Study

This study has several limitations. First, the validation process was based on expert and practitioner judgment; therefore, the findings cannot yet be interpreted as evidence of classroom effectiveness. Second, the construct validity claim is limited to expert-based appraisal of theoretical coherence and internal consistency, not empirical construct validation. Third, the model has not yet been tested with a large group of prospective science teachers in real hybrid classroom settings. Future research should address these limitations through practicality studies, quasi-experimental designs, and broader implementation across different science education contexts.

CONCLUSION

This study concludes that the Hybrid Project-Based Learning (Hybrid-PjBL) model integrated with Metacognitive Awareness and Local Wisdom–Scientific Curiosity is valid and reliable as an instructional model designed to support the procedural knowledge of prospective science teachers, particularly in biology education. The validity and reliability results indicate that the developed model fulfills initial content validity and expert-based construct coherence requirements, as demonstrated by the validation score ($r\alpha = 0.76$) and reliability coefficient ($\alpha = 0.86$). Furthermore, all supporting learning tools, including semester learning plans (RPS), learning scenarios, modules, student worksheets (LKPD), and assessment instruments, were also categorized as valid and reliable. The integration of metacognitive awareness and local wisdom–scientific curiosity within the Hybrid-PjBL framework contributes to creating meaningful, inquiry-oriented, and contextual learning experiences. The model encourages students to actively regulate their learning processes, develop problem-solving strategies, strengthen collaboration and communication skills, and engage in authentic scientific inquiry. The main contribution of this study is the development of an expert-validated instructional framework that connects hybrid learning, PjBL, metacognitive regulation, local wisdom, and scientific curiosity in one coherent model for prospective science teacher education. However, because this study was limited to the validation stage, the findings should not be interpreted as direct evidence that the model improves procedural knowledge. The model is considered appropriate for further testing to examine its practicality and effectiveness in real classroom settings.

RECOMMENDATIONS

Further studies are recommended to investigate the practicality and effectiveness of the Hybrid-PjBL model in real classroom settings. Practicality testing should examine lecturer readiness, student responses, time allocation, technological infrastructure, clarity of learning tools, and feasibility of implementing hybrid project activities. Future effectiveness studies should use experimental or quasi-experimental designs to examine the impact of the model on prospective science teachers' procedural knowledge, metacognitive awareness, scientific curiosity, collaboration, communication, and other 21st-century skills. Larger and more diverse participant groups are also needed to determine whether the model can be applied consistently across different science disciplines and institutional contexts. The implementation of the Hybrid-PjBL model should also be supported by adequate digital learning infrastructure, clear lecturer guidelines, contextual local wisdom resources, and assessment instruments that explicitly measure procedural knowledge. Researchers are encouraged to further explore how local wisdom can be transformed into authentic scientific problems without reducing its cultural meaning.

AUTHOR CONTRIBUTIONS

BF: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing–Original Draft Preparation. FPC: Methodology, Validation, Formal Analysis, Writing–Review & Editing, Supervision. MA: Conceptualization, Validation, Methodology, Writing–Review & Editing, Supervision. HH: Data Curation, Formal Analysis, Visualization, Writing – Review & Editing, Project Administration. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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