Journal of Current Studies in SDGs
Homepage : https://journal.i-ros.org/index.php/JOCSIS
Email : jocsis@i-ros.org

e-ISSN 3089-7564
Vol.2, No.2, June 2026

Product Design Worksheets as Procedural Scaffolding in the ScaPro-PjBL Model for Strengthening Pre-Service Physics Teachers' TPaCK toward SDG 4

Gaguk Resbiantoro[1,2*], Wasis[1], Wahono Widodo[1]

[1]Universitas Negeri Surabaya, Surabaya, Indonesia
[2]Universitas Islam Negeri Sayyid Ali Rahmatullah, Tulungagung, Indonesia

Check for updates OPEN ACCESS CC BY

DOI : https://doi.org/10.63230/jocsis.2.2.228

Sections Info

Article history:
Submitted: May 31, 2026
Final Revised: June 6, 2026
Accepted: June 11, 2026
First Available Online: June 26, 2026
Publication Date: June 27, 2026

Keywords:
Project-based learning;
Scaffolding in PjBL;
Worksheet practicality;
Worksheet roles;
Worksheet specification.

ABSTRACT

Objective: *To evaluate the validity and practicality of worksheets as a form of procedural scaffolding within the ScaPro-PjBL model for training TPaCK.* ***Method:*** *The design of these worksheets followed Plomp's (2013) design research stages: preliminary research, development/prototyping, and assessment. Developed alongside the innovative Scaffolded Product in Project-Based Learning (ScaPro-PjBL) model, the worksheets underwent expert review for validity and were piloted with 21 students in a limited pilot and 98 students in a broad pilot from two East Java campuses in Indonesia. Validity scores, reliability statistics (ICC(3, k) and Cronbach's Alpha), and practicality results were collected throughout these stages.* ***Results:*** *The worksheets were found to be valid, with an average validity score of 8.65 (very valid), an ICC(3, k) of 0.819 (good reliability), and an α of 0.839 (good reliability). Practicality was also confirmed, with an average score of 3.26-3.50 (very practical) in extensive trials. High reliability in practicality assessment was recorded using both $ICC_{(3,k)}$ and Cronbach's Alpha.* ***Novelty:*** *The six worksheets in this study were specifically designed as scaffolding in project-based learning to support the development of the ScaPro-PjBL model. The specifications for worksheet development are detailed in this article. This study contributes to SDG 4 (Quality Education) by providing structured, student-centered learning resources that enhance project-based learning implementation, promote higher-order thinking, and support equitable, high-quality science education.*

INTRODUCTION

According to the P21 Framework, information, media, and technology skills are essential 21st-century competencies (Battelle for Kids, 2019; Kayhan & Korkmaz, 2024; Rodríguez-Loinaz et al., 2024). To meet these needs, the learning process must integrate ICT (Claro et al., 2024). Teachers must drive this ICT integration as facilitators (Lindín et al., 2023; Claro et al., 2024). Pre-service teachers are trained to use ICT in learning and adapt to 21st-century transformations (Brown et al., 2021; Van Katwijk et al., 2023). The use of ICT in learning, including hybrid learning and digital tools, increases the effectiveness of the learning process, expands access to learning, and enables the development of 21st-century skills, which is aligned with SDG 4 (Akram et al., 2021; Anwar et al., 2025; Mat Salleh et al., 2025). The TPaCK framework represents their readiness for modern educational contexts (Mohebi, 2021; Carneiro et al., 2022) and is relevant for developing professional competences in pre-service physics teachers (Tondeur et al., 2021; Osorio Vanegas et al., 2025). Thus, TPaCK was selected to assess pre-service teachers' abilities to integrate ICT.

The development of technology-integrated learning is closely aligned with the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), which emphasizes inclusive, equitable, and high-quality education while promoting lifelong learning opportunities for all. Achieving this goal requires prospective teachers to develop digital pedagogical competencies that enable them to design meaningful, student-centered, and technology-enhanced learning experiences. Consequently, strengthening pre-service teachers' TPaCK through innovative instructional approaches, such as scaffolded Project-Based Learning (ScaPro-PjBL), supports the preparation of future educators who are capable of delivering effective science instruction and fostering higher-order thinking skills in digitally enriched learning environments.

TPaCK is a complex knowledge framework requiring transformative skills. It combines content knowledge (CK), pedagogy (PK), and technology (TK). TPaCK enables pre-service teachers to design and deliver effective ICT-based learning (Koehler & Mishra, 2009; Jiménez Sierra et al., 2023; Weidlich & Kalz, 2026). It covers selecting the right technology, adapting pedagogy to the content, and aligning instruction with educational contexts—including social factors, resources, and content (Brianza et al., 2022; Aslan et al., 2025). TPaCK is context-specific; knowledge must be applied to each educational situation for effective learning (Nguyen et al., 2025; Petko et al., 2025). Distance learning aligns with digital transformation in higher education and prepares teachers for 21st-century needs, as required by the University 4.0 model and the information industry (Gümüş, 2022; Abdulayeva, 2024). TPaCK in distance learning can be measured by assessing products such as lesson plans, microteaching, portfolios, and learning videos (Bilici et al., 2016; Akyuz, 2018; Wasis et al., 2018).

The urgency of TPaCK as a knowledge framework for pre-service teachers integrating ICT into learning sharply contrasts with existing conditions. Researchers have reported low TPaCK levels among students in Indonesia (A. Z. Rahmawati et al., 2021; Irwanto et al., 2022; Ginting et al., 2023; Putri et al., 2024; I. Rahmawati et al., 2024). Beyond Indonesia, studies from various countries have also identified low ICT integration skills among pre-service physics (science) teachers (Castéra et al., 2020; Bwalya & Rutegwa, 2023; Thy et al., 2023; Max et al., 2023; Mgeladze et al., 2024; Nkundabakura et al., 2024; Beltrán et al., 2025; Chindia et al., 2025; Mat Salleh et al., 2025; Petridou et al., 2025). These findings emphasize the need to intervene and train pre-service physics teachers in TPaCK.

According to Mouza (2016), one way to prepare pre-service physics teachers in TPaCK is to use a learning model in specific lectures with TPaCK-oriented outcomes. Lecturers can do this by following principles for improving TPaCK. Complementing this, Tondeur et al. (2020) recommend strategies to develop TPaCK, which are summarized in the SQD-Models. These strategies include (1) using teacher educators as role models; (2) reflecting on the role of technology in education; (3) learning how to use technology by design; (4) collaborating with peers; (5) scaffolding authentic technology experiences; and (6) providing continuous feedback. Notably, many SQD-Model recommendations align with Project-Based Learning (PjBL). For example, both emphasize students working on challenging problems, investigating in groups, answering authentic questions, describing projects, reflecting on the process, critiquing and improving work, and collaboratively creating public products (Edutopia, 2014; Larmer et al., 2015). However, PjBL does not fully meet all SQD-Model recommendations. In particular, it falls short in scaffolding authentic technology experiences, as several studies note. Common obstacles include students lacking adequate knowledge or intellectual foundation (Dag & Durdu, 2017; Zhang & Ma, 2023), insufficient guidance on device use (Rees Lewis et al., 2018; A. Rahmawati et al., 2020), and inadequate support during the PjBL process (Dag & Durdu, 2017). Consequently, researchers recommend providing structured scaffolding in PjBL to help students complete projects effectively (Dag & Durdu, 2017; Denton et al., 2021; Erviana et al., 2022).

Research demonstrates the role of scaffolding in Project-Based Learning (PjBL). It helps students integrate multiple disciplinary perspectives consistent with TPaCK. Forms of scaffolding include supervision, structured project planning (MacLeod & van der Veen, 2020); step-by-step feedback, reflective questions, group discussions (Z. Li et al., 2024; Jia et al., 2025); modeling, guided inquiry, and project templates (Pokharel, 2021; Padmadewi et al., 2023; Mallibhat, 2024). To provide authentic technology experiences, this study used procedural scaffolding through a project guide with clear steps, which aided students' understanding of the task flow and specifications (MacLeod & van der Veen, 2020; Padmadewi & Artini, 2023; Pokharel, 2023). The main scaffolding tool is a product design worksheet that supports the scaffolded product model (ScaPro-PjBL). ScaPro-PjBL systematically integrates PjBL and scaffolding to train future physics teachers in TPaCK.

This study contributes to the literature by proposing scaffolding for TPaCK training within PjBL contexts. The scaffolding is operationalized through worksheets for product design and TPaCK practice. The objectives of this research are: (1) to evaluate the validity of the worksheet as procedural scaffolding within the ScaPro-PjBL model, and (2) to assess its practicality in supporting TPaCK training utilizing the ScaPro-PjBL approach.

RESEARCH METHOD

This research is part of developing an innovative model grounded in Project-Based Learning (PjBL). The model requires structured scaffolding to train pre-service physics teachers in TPaCK for distance learning environments. The worksheet design follows the stages of preliminary research, development or prototyping, and assessment (Plomp, 2013). This article reports preliminary results from all stages up to the extensive trial, focusing on the worksheet design's specification, validity, and practicality. In training TPaCK, the ScaPro-PjBL model involves students completing TPaCK product projects, such as online lesson plans, digital worksheets, explanatory videos, and application-based formative evaluations. The worksheet design is based on preliminary research and used to evaluate its validity and practicality. Six worksheets were developed: (1) online learning planning framework, (2) pedagogical framework for video narrative scenario writing, (3) learning video storyboards, (4) digital student worksheet planning, (5) online discussion forum planning, and (6) application-based formative evaluation planning.

Three physics education experts reviewed the worksheet design's validity, following Nieveen & Folmer (2013) and Ramezani & Mostafavi (2025) on evaluating learning interventions. The validation sheet used criteria aligned with the development specifications. Validators were rated on a scale from 1 (least valid) to 10 (most valid). Validity was based on the average score, categorized as follows: 1) $7.75 \le P \le 10$, very valid; 2) $5.50 \le P < 7.75$, valid; 3) $3.25 \le P < 5.50$, moderate; and 4) $1.00 \le P < 3.25$, less valid. Reliability was calculated using the intraclass correlation coefficient for a two-way mixed-effects absolute-agreement model with multiple raters (Koo & Li, 2016; Hove et al., 2022). ICC(3,k) criteria are: 0.9–1 (excellent), 0.75–0.9 (good), 0.5–0.75

(moderate), and 0–0.5 (poor) (Koo & Li, 2016). Cronbach's Alpha was also used to measure internal consistency for the validation instrument (Fraenkel et al., 2012). Cronbach's Alpha criteria: 0.9–1 (excellent), 0.70–0.9 (high), 0.5–0.70 (moderate), and 0–0.5 (low) (Hinton et al., 2014).

The worksheet's practicality was evaluated through limited and extensive trials using a questionnaire. Twenty-one students participated in the limited trial and ninety-eight in the extensive trial, all from the physics education programs at two campuses in East Java, Indonesia. Students rated each item on a scale of 1 to 4. Average scores determined practicality: 1) $3.25 \leq P \leq 4.00$, very practical; 2) $2.50 \leq P < 3.25$, practical; 3) $1.75 \leq P < 2.50$, less practical; 4) $1.00 \leq P < 1.75$, not practical. Reliability was assessed using ICC (3, k) and Cronbach's Alpha, as in the validity evaluation.

RESULTS AND DISCUSSION

Results

Based on preliminary research, including literature reviews and the development of conceptual and theoretical frameworks, specifications for student worksheets were developed to support the ScaPro-PjBL model. Table 1 presents five main aspects of a worksheet framework: (1) Didactic and Learning Scaffolding, which covers alignment with learning outcomes, logical activity flow, conceptual questions, project prompts, active involvement, and opportunities for idea development and application; (2) Completeness of Components and Appropriateness of Materials, which covers the completeness of components, suitability of materials and tasks, depth of material for students, support for examples and illustrations, and availability of success criteria or references; (3) Project Structure and Time Allocation, which emphasizes clear project stages, progress checkpoints, individual contributions, schedules, deadlines, and flexibility; (4) Worksheet Design and Visual Presentation, which includes readable fonts, clear visual layout, relevant illustrations or infographics, and workspace for students; and (5) Language, Sentences, and Clarity of Instructions, which focuses on correct, simple language, clear instructions and steps, and consistent field terminology. Each aspect contains specific points to clarify the worksheet design, and together they form a cohesive framework.

Table 1. Worksheets specifications for the ScaPro-PjBL model

Dimension	Aspect	Item
Content	Didactic and Learning Scaffolding	1. Matches learning outcomes (Keck et al., 2021; Olayta, 2022; Dwikoranto et al., 2024; Juliana et al., 2024)
		2. Clear activity sequence (Choo, 2012; Hsu et al., 2015; Keck et al., 2021; Sánchez et al., 2025)
		3. Includes conceptual and project questions (Choo, 2012; Hsu et al., 2015; Syamsurizal et al., 2023; J. Li et al., 2026)
		4. Student participation in projects (Hsu et al., 2015; Byrd & Camba, 2020; Olayta, 2022; J. Li et al., 2026)
		5. Encourages idea development and use (Byrd & Camba, 2020; J. Li et al., 2026)
	Completeness of Components and Appropriatene	6. All worksheet parts included (Olayta, 2022; Juliana et al., 2024)
		7. Materials and tasks are suitable (Choo, 2012; Hsu et al., 2015; Hartini et al., 2020; Syamsurizal et al., 2023; Juliana et al., 2024)

Dimension	Aspect	Item
	ss of Materials	8. Material difficulty matches students' levels (Hartini et al., 2020; Keck et al., 2021; Syamsurizal et al., 2023; Sánchez et al., 2025) 9. Provides relevant examples (Olayta, 2022; Syamsurizal et al., 2023; Dwikoranto et al., 2024; Yan et al., 2025) 10. Clear success criteria (Widodo et al., 2019; J. Li et al., 2026)
Presentation	Project Structure and Time Allocation	11. Structured project stages (Byrd & Camba, 2020; J. Li et al., 2026) 12. Track progress and contributions (Buffalari, 2022; J. Li et al., 2026) 13. Timeframes specified (Buffalari, 2022; J. Li et al., 2026) 14. Flexible worksheet use (Byrd & Camba, 2020; J. Li et al., 2026)
	Worksheet Design and Visual Presentation	15. Fonts are easy to read (Olayta, 2022; Mery Berlian et al., 2023; Dwikoranto et al., 2024) 16. Clear visual design (Olayta, 2022; Mery Berlian et al., 2023; Dwikoranto et al., 2024) 17. Illustrations support content (Olayta, 2022; Mery Berlian et al., 2023; Syamsurizal et al., 2023; Dwikoranto et al., 2024) 18. Student work area included (Buffalari, 2022; J. Li et al., 2026)
Language	Language, Sentences, and Clarity of Instructions	19. Language is simple and correct (Mery Berlian et al., 2023; Dwikoranto et al., 2024) 20. Questions and instructions are clear (Choo, 2012; Hsu et al., 2015; Buffalari, 2022) 21. Clear work steps (Choo, 2012; J. Li et al., 2026) 22. Consistent terminology used (Mery Berlian et al., 2023; Dwikoranto et al., 2024)

The ScaPro-PjBL model has six phases, namely: 1) starting with essential questions; 2) designing a project with a timeline and checkpoints; 3) providing tutorials on subject-specific techniques and methods; 4) monitoring the project progress; 5) assessing and publishing the product; and 6) reflecting on work experience. The developed worksheets play a dominant role in phases 2-4 of the ScaPro-PjBL model. The worksheet specifications formulated are directly relevant to the implementation of these phases, as presented in Table 2.

Table 2. Mapping of worksheet specification items to the ScaPro-PjBL syntax model

Phase	Activity Focus	Appropriate Items
Phase 2: Designing a project with a timeline and checkpoints	Students identify products based on four TPaCK indicators in distance learning. They determine material and technical skill needs, develop a timeline, set checkpoints, and divide labor. They receive worksheets 1–6 to guide product design.	1, 2, 3, 4, 6, 7, 8, 10, 11, 12, 13
Phase 3: Providing tutorials on subject-specific techniques and methods	Students present their worksheets. The instructor synchronizes learning objectives, monitors the timeline, and explains technical requirements. The instructor provides tutorials on videography, editing, online testing, Google Workspace, and learning videos.	1, 3, 5, 7, 8, 9

Phase	Activity Focus	Appropriate Items
Phase 4: Monitoring the project progress	The instructor encourages collaboration and asks students to complete checkpoints. The instructor monitors progress and gives feedback on any challenges.	4, 10, 11, 12, 13

Table 3. Validity result for pre-service teacher worksheet

No.	Type of Worksheets	P	K	ICC (3,k)	K	α	K
1	Creating an online learning plan	8.61	SV	0.845	Good	0.848	Good
2	Outlining pedagogical principles and writing video narrative scenarios	8.65	SV	0.798	Good	0.832	Good
3	Developing a learning video storyboard	8.54	SV	0.856	Good	0.867	Good
4	Planning digital student worksheets	8.63	SV	0.845	Good	0.869	Good
5	Structuring online discussion forums	8.75	SV	0.789	Good	0.816	Good
6	Creating application-based formative evaluations	8.68	SV	0.779	Good	0.804	Good
	Average	**8.65**	**SV**	**0.819**	**Good**	**0.839**	**Good**

Note: ICC (3,k) = Intraclass Correlation Coeficient (Two-Way Mixed Effects, Mean of k Raters); α = Cronbach's Alpha; P = validity score; K = Category; SV = Very Valid

The data in Table 3 show that the validity scores for each worksheet range from 8.54 to 8.75, indicating Very Valid (SV). The average validity score for the entire worksheet is 8.65, with an average ICC(3,k) of 0.819 and an average Cronbach's Alpha of 0.839, both in the good reliability category. Worksheets I through VI all demonstrate consistently high validity scores, meeting the Very Valid criteria across all aspects. Furthermore, the ICC and Cronbach's Alpha values indicate absolute agreement and good internal consistency across all worksheets. All worksheets have met the validity achievement criteria (validity scores ≥ 5.50), confirming that they fulfill didactic aspects, serve as learning scaffolds, and meet standards for component completeness, material suitability, project structure, time allocation, design, visual presentation, and instructional clarity.

Table 4. Worksheets practicallity in trial classes

No	Dimension	Average Score / Criteria	Limited Trial Class	Extensive Trial Class A	B	C	D
1	Function as a work tool & process guide	P	2.66	3.34	3.40	3.26	3.27
		Category	Practical	SP	SP	SP	SP
		α - ICC	0.863	0.933	0.920	0.940	0.921
		Category	Good	Excellent	Excellent	Excellent	Excellent
2	Suitability for the role of ScaPro-PjBL and scaffolding	P	2.69	3.42	3.65	3.33	3.32
		Category	Practical	SP	SP	SP	SP
		α - ICC	0.822	0.915	0.853	0.872	0.907
		Category	Good	Excellent	Good	Good	Excellent
3	Involvement and support in the	P	2.74	3.49	3.50	3.32	3.33
		Category	Practical	SP	SP	SP	SP

No	Dimension	Average Score / Criteria	Limited Trial Class	Extensive Trial Class			
				A	B	C	D
	collaborative process	α - ICC	0.750	0.896	0.908	0.860	0.889
		Category	Good	Good	Excellent	Good	Good
4	Ability to support TPaCK product development	P	2.69	3.38	3.38	3.27	3.36
		Category	Practical	SP	SP	SP	SP
		α - ICC	0.780	0.859	0.903	0.840	0.858
		Category	Good	Good	Excellent	Good	Good

Note: α - ICC = α for limited trial - ICC for extensive trial; ICC = Intraclass Correlation Coefficients; P = average practicality score; SP = very practical

The practicality score of the worksheet was assessed across four dimensions: function as a work tool and process guide; suitability for the role of ScaPro-PjBL and scaffolding; involvement and support in the collaborative process; and ability to support the development of TPaCK products (see Table 4). In the limited trial, each dimension scored 2.66–2.74, indicating practicality. In the extensive test, all classes achieved higher average scores (3.26–3.65), were rated as very practical (SP), and showed high reliability (α = 0.853–0.933). The suitability for the role of ScaPro-PjBL and scaffolding earned the highest score in the extensive test (3.32–3.65, SP), while the function as a work tool and process guide dimension reached 3.26–3.40, indicating the usefull worksheets. All dimensions increased from limited to extensive trial, confirming the worksheet's usability, relevance, support for collaboration, and ability to facilitate TPaCK product development.

The extensive trial across all classes yielded higher scores than the limited trial. This indicates the worksheet was better received after improvements were made following the limited trial. The function dimension as a work tool and process guide rose from 2.66 in the limited trial to 3.26–3.40 in the extensive trial. The suitability dimension for ScaPro-PjBL & scaffolding increased from 2.69 to 3.32–3.65. Involvement and support in collaborative processes rose from 2.74 to 3.32–3.50. The ability to support TPaCK product development also improved, climbing from 2.69 in the limited trial to 3.27–3.38 in the extensive trial.

Discussion

The worksheets developed in this research include: worksheet I: Online Learning Planning Framework; worksheet II: Pedagogical Framework for Video Narrative Scenario Writing Principles; worksheet III: Video Storyboard; worksheet IV: Digital Student Worksheet Planning; worksheet V: Discussion Forum Planning; and worksheet VI: Designing Digital Platform-Based Formative Evaluations. The worksheet validation results, as shown in Table 2, indicate that the developed worksheets meet the criteria for high validity. These results indicate that the worksheets can support the implementation of the SaPro-PjBL model.

The worksheets serve as procedural scaffolding during the implementation of the ScaPro-PjBL model. The worksheets were designed to address potential student difficulties in completing projects, as Choo (2012) stated. The activities in each worksheet are oriented towards product development and planning student TPaCK performance demonstrations. The worksheets were implemented in phase 2, when students began designing and planning projects. Gradually, students engage with the worksheet activities and may reach their zone of proximal development (ZPD). Thus, by the time they enter phase 3, they already understand the need for subject-specific tutorials to complete their projects. Continuing into phase 4, the worksheet serves as a monitoring sheet for students' project stages. This aligns with the views of Choo (2012) and Buffalari (2022), who argue that worksheets enable lecturers to monitor students' project progress. This worksheet's role is very helpful for lecturers, making the implementation of the ScaPro-PjBL model much more efficient.

Due to TPaCK's complexity, worksheets can function as tools and guides for product development. Students found them practical, as shown in Table 4. Van Nooijen et al. (2024) also stated that worksheets help students by reducing assignment complexity and aiding completion. Students noted that worksheets supported group collaboration, lessening individual workload. This reflects the worksheet's role in enhancing group contribution and collaboration (Buffalari, 2022).

Worksheets facilitate the project design phase (Phase 2 of the ScaPro-PjBL model) by directing students to align their products with intended learning outcomes, specified competency requirements, and the overall project direction. The inclusion of concept maps, formative questions, and scaffolded tasks in the worksheets elucidates foundational concepts prior to design determination, thereby ensuring that the project is rooted in a defined conceptual framework (Nurhidayah & Pratama, 2024; Pulagam et al., 2025). Worksheets further structure the workflow through systematic, modular steps, enabling students to discern potential products, assemble technical specifications, and organize the design process rigorously (Beltrán et al., 2025; Pernaa et al., 2025). Conceptual prompts and design questions foster critical thinking, promote creativity, and enrich group discussions relevant to project design (Santoso et al., 2021; Nurhidayah & Pratama, 2024). Explicit work structures, clearly articulated success criteria, defined timelines, established checkpoints, and demarcated member roles collectively minimize the risk of disproportionate group participation, thereby augmenting collaborative, measurable project design aligned with learning objectives (Buffalari, 2022; Beltrán et al., 2025; J. Li et al., 2026).

The project design phase in project-based learning directly supports SDG 4 by enhancing students' planning, collaboration, and task-allocation skills, thereby improving the quality of education (Yusupova et al., 2025). This phase enables students to use design thinking to address real-world SDG challenges, making learning relevant and sustainable (Petchamé et al., 2026). A model that encourages active student involvement in planning and decision-making reinforces contextual learning aligned with SDG 4 (Yusupova et al., 2025; Petchamé et al., 2026). Incorporating comprehensive planning, risk-sharing, and a focus on social value creation enhances project management and supports sustainability (Wang et al., 2025). Core skills such as communication, leadership, and teamwork are essential for embedding sustainability throughout a project, particularly its social dimension (Toljaga-Nikolić et al., 2020). Furthermore, sustainable project management systematically advances the achievement of SDGs (Soares et al., 2024). TPaCK products that integrate technology and pedagogy foster innovative learning. They enable teachers to adopt new methods that align with sustainable education goals (Velu et al., 2025). Creating content within TPaCK framework strengthens links between technology, content, and pedagogy. This also improves pre-service teachers' ICT skills and supports SDG indicators 4.4.1 and 4.7.1 (Lijo et al., 2022). Using the TPaCK framework to develop prototypes, products, and pedagogical practices encourages competence, creativity, and quality education in line with SDG 4.

Worksheets facilitate the tutorial phase (Phase 3 of the ScaPro-PjBL model) by providing conceptual and procedural orientation prior to product development. They should encompass more than procedural instructions; worksheets must pose questions, supply examples, and assign tasks that explicitly target specific learning outcomes, thereby sustaining alignment with the intended competencies (Adeniji & Baker, 2022; Toh, 2022; Robertson et al., 2025). Conceptual questions enable students to assess their comprehension, discern interrelationships among concepts, and explicate their reasoning before making technical decisions (Toh, 2022; Szalay et al., 2023; Robertson et al., 2025). Stepwise instructions, pertinent examples, and tasks calibrated to students' proficiency levels scaffold comprehension of discipline-specific techniques, methods, and procedures (Adeniji & Baker, 2022; Paxinou et al., 2022; Szalay et al., 2023). In sum, worksheets not only methodically guide students through tutorials but also foster the development of original ideas, deepen understanding, and facilitate deliberate design decisions (Toh, 2022; Szalay et al., 2023; Robertson et al., 2025).

Worksheets facilitate the fourth phase (monitoring the project progress) by subdividing the project into discrete stages. This structure enables instructors and students to systematically monitor progress (Schlegel et al., 2018; Byrd & Camba, 2020; J. Li et al., 2026). The success criteria in the worksheets clarify achievement standards and provide instructors with an explicit basis for evaluating progress (Byrd & Camba, 2020; J. Li et al., 2026). Timelines, deadlines, and checkpoints enable quantifiable monitoring, allowing students to compare attained milestones against the proposed plan (Roberts, 2021; Buffalari, 2022). Worksheets should also allocate space for documenting member contributions, ensuring that participation is recorded and evaluated objectively (Buffalari, 2022; Nurhidayah & Pratama, 2024; J. Li et al., 2026). Through this structure, worksheets serve both as a process control tool and as tangible evidence of progress, capturing workflow, accomplishments, delays, obstacles, and individual contributions (Roberts, 2021).

The practicality of student worksheets as instructional materials for TPaCK practice substantiates the ScaPro-PjBL model. Student responses categorize the worksheets as highly practical, as shown in Table 4. This finding corresponds with the nature of worksheets, which serve as hard scaffolds designed according to students' perceived difficulties prior to assignments (Choo, 2012). Within the ScaPro-PjBL model, worksheets delineate the procedures required for product completion, performance demonstration, and progress monitoring. They foster deeper cognitive engagement with products, synthesize essential conceptual and technical knowledge necessary for TPaCK and project execution, and facilitate student focus. This corroborates Buffalari's (2022) findings that worksheets in project-based learning positively influence students' expectations, group-work scheduling, and collaborative concerns. As scaffolds, cognitive worksheets direct attention to pertinent information (cueing) or facilitate the integration of new information with prior knowledge to optimize working memory usage (chunking) (van Nooijen et al., 2024).

Worksheets support ScaPro-PjBL implementation through their use as work tools, process guides, and scaffolding. They also foster engagement and collaboration and aid TPaCK product development. As process guides, worksheets offer step-by-step instructions that beginners can follow immediately (McKenna et al., 2017). Research has introduced design worksheets to help beginners learn how to design visualization systems. Other studies have strengthened evidence for worksheets' role in engaging and supporting collaborative processes (Remmen & Frøyland, 2014; Tupan et al., 2024;

Kalaitzidou et al., 2026). Previous research has shown that worksheets can support the PjBL approach, assist in producing computer-based learning artifacts (Grant & Branch, 2005), and contribute to achieving learning objectives through successful outputs or products (Aprida & Mayarni, 2023).

Overall, the results of this study indicate that the worksheet is valid and practical as teaching material. The worksheet supports the ScaPro-PjBL model, helps students understand the material more easily, fits various learning activities, and allows flexible use. High reliability shows observers rate it consistently, ensuring it can confidently support the ScaPro-PjBL model implementation. From the perspective of the Sustainable Development Goals (SDGs), the findings provide further evidence that scaffolded project-based learning supported by validated and practical worksheets contributes directly to SDG 4 (Quality Education). The worksheets facilitate technology-integrated, student-centered learning by guiding pre-service teachers through systematic project planning, implementation, and reflection while strengthening their Technological Pedagogical Content Knowledge (TPaCK). This structured scaffolding enhances higher-order thinking, collaboration, creativity, and digital competence, all of which are essential competencies for future educators in the twenty-first century. Therefore, the ScaPro-PjBL worksheets represent an effective instructional innovation for preparing digitally competent teachers and promoting sustainable improvements in the quality of teacher education.

CONCLUSION

Fundamental Finding: Based on expert evaluation and conducted trials, the worksheet has been declared valid and practical as supporting teaching material for the ScaPro-PjBL model in training TPaCK for pre-service student teachers. **Implication:** The validity and practicality specifications identified in this study provide a clear framework for researchers and educators seeking to develop similar instructional materials. These specifications can guide future studies in replicating or extending the ScaPro-PjBL model across different educational contexts. Furthermore, the findings contribute to SDG 4 (Quality Education) by providing evidence-based guidelines for designing technology-integrated, student-centered teaching materials that enhance teacher preparation, promote digital pedagogical competence, and support sustainable improvements in the quality of science education. **Limitation:** This research is limited to pre-service physics student teachers in a learning environment within the specific context of the targeted TPaCK, namely distance learning. **Future Research:** Further research can develop the worksheet for other content and contexts by adapting the specifications and practicality criteria based on student responses.

AUTHOR CONTRIBUTIONS

Gaguk Resbiantoro contributed to the conceptualization, methodology, investigation, data curation, formal analysis, visualization, and manuscript drafting. **Wasis** contributed to the research design, supervision, validation, manuscript review, and editing. **Wahono Widodo** contributed to the conceptual framework, supervision, interpretation of findings, manuscript review, and editing. All authors have read and approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors state that no financial or personal conflicts of interest exist that may have affected the content or findings of this research.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors declare that no artificial intelligence (AI) tools or other digital writing assistants were used in the preparation, analysis, or writing of this manuscript. All stages of the research process, including data analysis, interpretation, and manuscript writing, were conducted solely by the authors. The authors take full responsibility for the originality, accuracy, and integrity of the content presented in this article.

REFERENCES

Abdulayeva, A. B. (2024). Rapid foresight: Information technologies in Physics lessons. *Journal of Physics: Conference Series*, *2871*(1), 12012. https://doi.org/10.1088/1742-6596/2871/1/012012

Adeniji, S. M., & Baker, P. (2022). Worked-examples instruction versus van Hiele teaching phases: A demonstration of students' procedural and conceptual understanding. *Journal on Mathematics Education*, *13*(2), 337–356. https://doi.org/10.22342/jme.v13i2.pp337-356

Akram, H., Yingxiu, Y., Al-Adwan, A. S., & Alkhalifah, A. (2021). Technology integration in higher education during COVID-19: An assessment of online teaching competencies through technological pedagogical content knowledge model. *Frontiers in Psychology*, *12*, 736522. https://doi.org/10.3389/fpsyg.2021.736522

Akyuz, D. (2018). Measuring Technological Pedagogical Content Knowledge (TPACK) through performance assessment. *Computers and Education*, *125*(June), 212–225. https://doi.org/10.1016/j.compedu.2018.06.012

Anwar, Y., Widodo, A., Al fatih, Z., Kartika, D., Ariska, M., & Yusliani, N. (2025). Education for sustainable development based on technological pedagogical content knowledge in biology education: Assessing teachers' readiness. *Jurnal Pendidikan IPA Indonesia*, *14*(3). https://doi.org/10.15294/jpii.v14i3.22908

Aprida, H., & Mayarni, M. (2023). Efficiency of PjBL (Project Based Learning) model assisted by e-worksheet on student learning outcomes in science subjects. *Jurnal Penelitian Pendidikan IPA*, *9*(8), 6284–6291. https://doi.org/10.29303/jppipa.v9i8.4372

Aslan, S., Alanoğlu, M., & Karabatak, S. (2025). *Enhancing 21st-century teaching competencies: The key role of digital literacy in connecting pre-service teachers' TPACK. Information Development.* Advance online publication. https://doi.org/10.1177/02666669251315841

Battelle for Kids. (2019). *Framework for 21st century learning definitions.* Partnership for 21st Century Learning.

Beltrán, N., Fernández, A., Blanco, D., Martín, J. A., & Zapico, P. (2025). Enhancing project-based learning: A handoff-structured model for balanced roles. *International Journal of Mechanical Engineering Education. 0*(0). https://doi.org/10.1177/03064190251383880

Bilici, S. C., Guzey, S. S., & Yamak, H. (2016). Assessing pre-service science teachers' Technological Pedagogical Content Knowledge (TPACK) through observations and lesson plans. *Research in Science and Technological Education*, *34*(2), 237–251.

https://doi.org/10.1080/02635143.2016.1144050

Brianza, E., Schmid, M., Tondeur, J., & Petko, D. (2022). Situating TPACK: A systematic literature review of context as a domain of knowledge. *Contemporary Issues in Technology and Teacher Education*, *22*(4), 707–753. https://www.learntechlib.org/p/221446

Brown, A. L., Myers, J., & Collins, D. (2021). How pre-service teachers' sense of teaching efficacy and preparedness to teach impact performance during student teaching. *Educational Studies, 47*(1), 38–58. https://doi.org/10.1080/03055698.2019.1651696

Buffalari, D. (2022). Structured worksheets: Simple active learning strategies to increase transparency and promote communication. *Journal of Undergraduate Neuroscience Education*, *20*(2), A241–A253. https://doi.org/10.59390/VOHJ7109

Bwalya, A., & Rutegwa, M. (2023). Technological pedagogical content knowledge self-efficacy of pre-service science and mathematics teachers: A comparative study between two Zambian universities. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(2), em2222. https://doi.org/10.29333/ejmste/12845

Byrd, V. L., & Camba, J. D. (2020). A worksheet method for developing research questions: An examination of three graduate student cohorts. In *2020 IEEE Frontiers in Education Conference (FIE)*. IEEE. https://doi.org/10.1109/fie44824.2020.9273883

Carneiro, M., Soares, A., Catarino, P., & Reis, M. (2022). Technology integration models in mathematics teaching: Analysis of quality criteria. In *EDULEARN Proceedings*. IATED. https://doi.org/10.21125/edulearn.2022.1164

Castéra, J., Marre, C. C., Yok, M. C. K., Sherab, K., Impedovo, M. A., Sarapuu, T., Pedregosa, A. D., Malik, S. K., & Armand, H. (2020). Self-reported TPACK of teacher educators across six countries in Asia and Europe. *Education and Information Technologies*, *25*(4), 3003–3019. https://doi.org/10.1007/s10639-020-10106-6

Chindia, B., Wawire, S. N., & Henson, H. (2025). Secondary science teacher preparation: A scoping review of challenges, structures, and interventions. *Advances in Educational Research and Evaluation*, *6*(1), 318–331. https://doi.org/10.25082/aere.2025.01.002

Choo, S. S. Y. (2012). Scaffolding in problem-based learning. In G. O'Grady, E. H. J. Yew, K. P. L. Goh, & H. G. Schmidt (Eds.), *One-Day, One-Problem: An Approach to Problem-based Learning* (pp. 167–184). Springer Singapore. https://doi.org/10.1007/978-981-4021-75-3_8

Claro, M., Castro-Grau, C., Ochoa, J. M., Hinostroza, J. E., & Cabello, P. (2024). Systematic review of quantitative research on digital competences of in-service school teachers. *Computers and Education*, *215*(July), 105030. https://doi.org/10.1016/j.compedu.2024.105030

Dag, F., & Durdu, L. (2017). Pre-service teachers' experiences and views on project-based learning processes. *International Education Studies*, *10*(7), 18–39. https://doi.org/10.5539/ies.v10n7p18

Denton, A., Hodara, M., Petrokubi, J., Merrill, B., & Velie, Z. (2021). *Preparing teachers for project based learning*. Education Northwest.

Dwikoranto, D., Surasmi, W. A., Suparti, S., & Setiani, R. (2024). Assessing the validity and effectiveness of student worksheets and creativity tests in enhancing the creativity of open university students. *Prisma Sains : Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika dan IPA IKIP Mataram*, *12*(2), 376.

https://doi.org/10.33394/j-ps.v12i2.9979

Edutopia. (2014). Five keys to rigorous project-based learning. In *Edutopia The George Lucas Educational foundation*. https://www.edutopia.org/video/5-keys-rigorous-project-based-learning

Erviana, V. Y., Sintawati, M., Bhattacharyya, E., Habil, H., & Fatmawati, L. (2022). The effect of project-based learning on technological pedagogical content knowledge among elementary school pre-rervice teacher. *Pegem Journal of Education and Instruction*, *12*(2), 151–156. https://doi.org/10.47750/pegegog.12.02.15

Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education* (8th ed.). McGraw-Hill.

Ginting, F. W., Sakdiah, H., Widya, & Unaida, R. (2023). Analysis of the need for development of virtual reality-based learning media to build Technological Pedagogical and Content Knowledge (TPACK) competencies for prospective physics teachers. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 12098–12103. https://doi.org/10.29303/jppipa.v9i12.6163

Grant, M. M., & Branch, R. M. (2005). Project-based learning in a middle school. *Journal of Research on Technology in Education*, *38*(1), 65–98. https://doi.org/10.1080/15391523.2005.10782450

Gümüş, A. (2022). Twenty-first-century teacher competencies and trends in teacher training. In *Educational Theory in the 21st Century* (pp. 243–267). Springer Nature Singapore. https://doi.org/10.1007/978-981-16-9640-4_11

Hartini, S., Mariani, I., Misbah, & Sulaeman, N. F. (2020). Developing of students worksheets through STEM approach to train critical thinking skills. *Jurnal Physics Conference Series*, *1567*(4), 42029. https://doi.org/10.1088/1742-6596/1567/4/042029

Hinton, P. R., McMurray, I., & Brownlow, C. (2014). *SPSS explained* (2nd ed.). Routledge.

Hove, D. ten, Jorgensen, T. D., & van der Ark, L. A. (2022). Updated guidelines on selecting an intraclass correlation coefficient for interrater reliability, with applications to incomplete observational designs. *Psychological Methods*, *29*(5), 967–979. https://doi.org/10.1037/met0000516

Hsu, Y.-S., Lai, T.-L., & Hsu, W.-H. (2015). A design model of distributed scaffolding for inquiry-based learning. *Research in Science Education*, *45*(2), 241–273. https://doi.org/10.1007/s11165-014-9421-2

Irwanto, I., Redhana, I. W., & Wahono, B. (2022). Examining perceptions of technological pedagogical content knowledge (TPACK): A perspective from Indonesian pre-service teachers. *Jurnal Pendidikan IPA Indonesia*, *11*(1), 142–154. https://doi.org/10.15294/jpii.v11i1.32366

Jia, J., Ghazali, N. E., Su, E., & Ming, L. (2025). The impact of scaffolding on the development of metacognitive skills in project-based engineering learning. *Asean Journal of Engineering Education*, *9*(1), 1–10. https://doi.org/10.11113/ajee2025.9n1.177

Jiménez Sierra, Á. A., Ortega Iglesias, J. M., Cabero-Almenara, J., & Palacios-Rodríguez, A. (2023). Development of the teacher's technological pedagogical content knowledge (TPACK) from the lesson study: A systematic review. *Frontiers in Education*, *8*, 1078913. https://doi.org/10.3389/feduc.2023.1078913

Juliana, N., Ampera, D., Farihah, Baharuddin, & Sinukaban, V. Y. (2024). Digital student worksheets to improving students' learning independence. *Jurnal Education Technolology*, *8*(1), 31–41. https://doi.org/10.23887/jet.v8i1.75433

Kalaitzidou, A., Kougiourouki, M., Masali, Z., & Passa, E. (2026). Primary education teachers' views on the pedagogical use of worksheets in natural sciences. *European Journal of Education and Pedagogy*, *7*(2), 12–18. https://doi.org/10.24018/ejedu.2026.7.2.31038

Kayhan, O., & Korkmaz, Ö. (2024). *Measuring 21st-century competencies: Development and validation of the information, media, and technology skills self-efficacy scale. Information Development.* Advance online publication. https://doi.org/10.1177/02666669241297661

Keck, M., Stoll, E., & Kammer, D. (2021). A didactic framework for analyzing learning activities to design InfoVis courses. *IEEE Comput. Graph. Appl.*, *41*(6), 80–90. https://doi.org/10.1109/MCG.2021.3115416

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70. https://doi.org/10.1016/j.compedu.2009.07.009

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine*, *15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Larmer, J., Mergendoller, J., & Boss, S. (2015). *Setting the standard for project based learning: A proven approach to rigorous classroom instruction*. Association for Supervision and Curriculum Development (ASCD).

Li, J., Goei, S. L., van Joolingen, W., & Raijmakers, M. (2026). Shaping maker education through design thinking: A lesson study perspective. *Thinking Skills Creativity*, *59*, 101957. https://doi.org/10.1016/j.tsc.2025.101957

Li, Z., Oon, P.-T. E., & Chai, S. (2024). Examining the impact of teacher scaffolding in the knowledge building environment: Insights from students' interaction patterns, social epistemic networks, and academic performance. *Education and Information Technologies*, *29*(14), 18501–18532. https://doi.org/10.1007/s10639-024-12535-z

Lijo, R., Quevedo, E., Castro, J. J., & Horta, R. (2022). Assessing users' perception on the current and potential educational value of an electrical engineering YouTube channel. *IEEE Access*, *10*, 8948–8959. https://doi.org/10.1109/access.2021.3139305

Lindín, C., Engel, A., Gràcia, M., Rivera-Vargas, P., & Rubio, M. J. (2023). Literature review on emerging educational practices mediated by digital technologies in higher education, based on academic papers. *SAGE Open*, *13*(4). https://doi.org/10.1177/21582440231204677

MacLeod, M., & van der Veen, J. T. (2020). Scaffolding interdisciplinary project-based learning: a case study. *European Journal of Engineering Education*, *45*(3), 363–377. https://doi.org/10.1080/03043797.2019.1646210

Mallibhat, K. (2024). Scaffolding models in a project-based learning course - A case study. *Journal of Engineering Education Transformations*, *37*, 796–803. https://journaleet.in/index.php/jeet/article/view/2504

Mat Salleh, M. F., Basri, A. S. M., Ismail, M. H., Zulkipli, Z. A., Abdullah, N., Maaruf, S. Z., Hadiyanti, L. N., Alimah, S., & W. H. Nugrahaningsih. (2025). Assessing pre-service science teachers' Technological Pedagogical Content Knowledge (TPACK) in the hybrid learning environment. *Jurnal Pendidikan IPA Indonesia*, *14*(1). https://doi.org/10.15294/jpii.v14i1.16819

Max, A.-L., Weitzel, H., & Lukas, S. (2023). Factors influencing the development of pre-service science teachers' technological pedagogical content knowledge in a pedagogical makerspace. *Frontries in Education*, *8*.

https://doi.org/10.3389/feduc.2023.1166018
McKenna, S., Lex, A., & Meyer, M. (2017). Worksheets for guiding novices through the visualization design process. In *arXiv [cs.HC]*. https://doi.org/10.48550/arXiv.1709.05723
Mery Berlian, Dinda, D. S., & Rian Vebrianto. (2023). Instruments development for measuring student worksheet media based on scientific approaches. *Jurnal Pijar Mipa*, *18*(2), 163–169. https://doi.org/10.29303/jpm.v18i2.4537
Mgeladze, A., Kapanadze, M., & Chakhaia, L. (2024). From measuring to action: The next steps in Physics teachers' technological pedagogical content knowledge. *Science Education International*, *35*(4), 429–438. https://www.icaseonline.net/journal/index.php/sei/article/view/1078
Mohebi, L. (2021). Theoretical models of integration of interactive learning technologies into teaching: A systematic literature review. *International Journal of Learning, Teaching and Educational Research*, *20*(12), 232–254. https://doi.org/10.26803/ijlter.20.12.14
Mouza, C. (2016). Developing and assessing TPACK among pre-service teachers: A synthesis of research. In M. C. Herring, P. Mishra, & M. J. Koehler (Eds.), *Handbook of Technological Pedagogical Content Knowledge (TPACK) for Educators* (Second Ed., pp. 169–190). Routledge.
Nguyen, V. L., Hang, C. T. T., Nguyen, N. T., & Sang, H. T. (2025). Contextual knowledge and TPACK: Evidence from a global south setting. *Computers and Education Open*, *9*, 100290. https://doi.org/https://doi.org/10.1016/j.caeo.2025.100290
Nieveen, N., & Folmer, E. (2013). Formative evaluation in educational design research. In T. Plomp & N. Nieveen (Eds.), *Educational Design Research* (pp. 153–169).
Nkundabakura, P., Nsengimana, T., Uwamariya, E., Nyirahabimana, P., Nkurunziza, J. B., Mukamwambali, C., Dushimimana, J. C., Nsabayezu, E., Twahirwa, J. N., & Ndihokubwayo, K. (2024). Contribution of Continuous Professional Development (CPD) training programme on Rwandan secondary school mathematics and science teachers' pedagogical, technological, and content knowledge. *Education Information Technology*, *29*(4), 4969–4999. https://doi.org/10.1007/s10639-023-11992-2
Nurhidayah, D., & Pratama, A. T. (2024). Students' e-worksheet based on project and character of Pancasila through environmental issues: What are the characteristics? *Research and Development in Education (RaDEn)*, *4*(1), 113–126. https://doi.org/10.22219/raden.v4i1.32182
Olayta, J. A. L. (2022). Worksheets for the improvement of technical drafting skills of electrical installation and maintenance students. *International Journal of Research Publications*, *104*(1), 142–159. https://doi.org/10.47119/ijrp1001041720223498
Osorio Vanegas, H. D., Segovia Cifuentes, Y. de M., & Sobrino Morrás, A. (2025). Educational technology in teacher training: A systematic review of competencies, skills, models, and methods. *Education Science (Basel)*, *15*(8), 1036. https://doi.org/10.3390/educsci15081036
Padmadewi, N. N., Artini, L. P., Ratminingsih, N. M., Suhardiana, I. P. A., Zamzam, A., & Juniarta, P. A. K. (2023). Designing project-based learning in research proposal writing: Its effect, problems, and scaffolding utilized. *Studies in English Language and Education*, *10*(2), 841–862. https://doi.org/10.24815/siele.v10i2.27408
Paxinou, E., Georgiou, M., Kakkos, V., Kalles, D., & Galani, L. (2022). Achieving

educational goals in microscopy education by adopting virtual reality labs on top of face-to-face tutorials. *Research in Science & Technological Education*, *40*(3), 320–339. https://doi.org/10.1080/02635143.2020.1790513

Pernaa, J., Ambrož, M., & Haatainen, O. (2025). Pedagogical resources for conducting STEM engineering projects in chemistry teacher education: A design-based research approach. *Education Science (Basel)*, *15*(9), 1196. https://doi.org/10.3390/educsci15091196

Petchamé, J., Novkovic, D., Fox, P., Kinnear, L., & Torres-Kompen, R. (2026). SDG-driven entrepreneurship through technology solutions in higher education enhanced by problem-based learning: An active learning approach in a smart classroom environment. *Sustainability*, *18*(4), 1849. https://doi.org/10.3390/su18041849

Petko, D., Mishra, P., & Koehler, M. J. (2025). TPACK in context: An updated model. *Computers and Education Open*, *8*, 100244. https://doi.org/10.1016/j.caeo.2025.100244

Petridou, E., Molohidis, A., & Hatzikraniotis, E. (2025). Contextual influences on self-assessed TPACK: A comparison of physics undergraduates and in-service science teachers. *Trends in Higher Education*, *4*(4), 76. https://doi.org/10.3390/higheredu4040076

Plomp, T. (2013). Educational design research: An introduction. In T. Plomp & N. Nieveen (Eds.), *Educational Design Research* (pp. 10–51). Netherlands Institute for Curriculum Development (SLO). https://doi.org/10.1007/978-1-4614-3185-5_11

Pokharel, S. (2021). Providing project management knowledge and skills through scaffolding and project-based learning strategy. *Journal of Engineering Design and Technology*, *21*(4), 1153–1172. https://doi.org/10.1108/jedt-07-2021-0343

Pulagam, V., Dailey, A., Stephenson, D., & Terán, J. E. (2025). Engineering a sustainable future: Integrating carbon neutrality and research-based learning into first-year engineering courses. *Journal Chemistry Education*, *102*(12), 5095–5105. https://doi.org/10.1021/acs.jchemed.5c01009

Putri, S. A., Damayanti, P., Nuryadin, A., & Sulaeman, N. F. (2024). Online microteaching: Unveiling female pre-service physics teachers Technological Pedagogical and Content Knowledge (TPACK). *KnE Social Science 9*(13), 16015. https://doi.org/10.18502/kss.v9i13.16015

Rahmawati, A., Suryani, N., Akhyar, M., & Sukarmin. (2020). Technology-integrated project-based learning for pre-service teacher education: A systematic literature review. *Open Engineering*, *10*(1), 620–629. https://doi.org/10.1515/eng-2020-0069

Rahmawati, A. Z., Haryanto, Z., & Sulaeman, N. F. (2021). Digital literacy of indonesian prospective physics teacher: Challenges beyond the pandemic. *Journal Physics Conference Series*, *2104*(1), 12004. https://doi.org/10.1088/1742-6596/2104/1/012004

Rahmawati, I., Kurniawan, B. R., & Sofianto, E. W. N. (2024). How do physics teacher candidates use TPACK in making physics learning videos? In *AIP Conference Proceedings* (Vol. 3070, p. 20021). AIP Publishing. https://doi.org/10.1063/5.0201079

Ramezani, S. G., & Mostafavi, Z. S. (2025). Developing and validating a comprehensive scale for accreditation standards and quality assurance in e - learning institutions. In *Education and Information Technologies* (Vol. 30, Issue 15). Springer US. https://doi.org/10.1007/s10639-025-13587-5

Rees Lewis, D. G., Easterday, M. W., Harburg, E., Gerber, E. M., & Riesbeck, C. K. (2018). Overcoming barriers between volunteer professionals advising project-based learning teams with regulation tools. *British Journal of Educational Technology*, *49*(3), 354–369. https://doi.org/10.1111/bjet.12550

Remmen, K. B., & Frøyland, M. (2014). Implementation of guidelines for effective fieldwork designs: Exploring learning activities, learning processes, and student engagement in the classroom and the field. *International Research in Geographical and Environmental Education*, *23*(2), 103–125. https://doi.org/10.1080/10382046.2014.891424

Roberts, J. S. (2021). Integrating metacognitive regulation into the online classroom using student-developed learning plans. *Journal of Microbiology & Biology Education, 22*(1), 2409. https://doi.org/10.1128/jmbe.v22i1.2409

Robertson, A. D., Goodhew, L. M., Bauman, L. C., Alesandrini, A. T., & Heron, P. R. L. (2025). Developing and assessing research-based, resources-oriented instructional materials: Attending to conceptual resources in (ACORN) physics tutorials. *Physics Reiew Physics Education Research*, *21*(2). https://doi.org/10.1103/zsqv-4py5

Rodríguez-Loinaz, G., Ametzaga-Arregi, I., & Palacios-Agundez, I. (2024). ICT tools and citizen science: A pathway to promote science learning and education for sustainable development in schools. *Journal of Biological Education*, *58*(3), 609–625. https://doi.org/10.1080/00219266.2022.2092192

Sánchez, A., Ledezma, C., & Font, V. (2025). A proposal of integration of universal design for learning and didactic suitability criteria. *Education Science (Basel)*, *15*(7), 909. https://doi.org/10.3390/educsci15070909

Santoso, A. M., Primandiri, P. R., Zubaidah, S., & Amin, M. (2021). The development of students' worksheets using Project Based Learning (PjBL) in improving Higher Order Thinking skills (HOTs) and time management skills of students. *Journal Physics Conference Series*, *1806*(1), 12173. https://doi.org/10.1088/1742-6596/1806/1/012173

Schlegel, E., McLeod, K. B. D., & Selfridge, N. J. (2018). Practical tips for successful implementation of educational innovations: Project management tools for health professional educators. *Mededpublish*, *7*, 105. https://doi.org/10.15694/mep.2018.0000105.1

Syamsurizal, Irdawati, Violita, Afni, R. S., & Sholichin, M. (2023). Validity and practicality of SSCS-based student worksheet on ecology material and environmental change. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11394–11400. https://doi.org/10.29303/jppipa.v9i12.4444

Szalay, L., Tóth, Z., Borbás, R., & Füzesi, I. (2023). Scaffolding of experimental design skills. *Chemistry Education Research and Practice*, *24*(2), 634–649. https://doi.org/10.1039/D2RP00260D

Thy, S., Im, R., & Iwayama, T. (2023). Examining cambodian high school science teachers' perception of Technological Pedagogical Content Knowledge (TPACK). *Jurnal Science Education*, *4*(1), 1–13. https://doi.org/10.56003/jse.v4i1.232

Toh, T. L. (2022). Teachers' instructional goals and their alignment to the school mathematics curriculum: A case study of the calculus instructional material from a Singapore pre-university institution. *Mathematics Education Research Journal, 34*(3), 631–659. https://doi.org/10.1007/s13394-022-00419-9

Toljaga-Nikolić, D., Todorović, M., Dobrota, M., Obradović, T., & Obradović, V. (2020). Project management and sustainability: Playing trick or treat with the planet.

Sustainability, *12*(20), 8619. https://doi.org/10.3390/su12208619

Tondeur, J., Petko, D., Christensen, R., Drossel, K., Starkey, L., Knezek, G., & Schmidt-Crawford, D. A. (2021). Quality criteria for conceptual technology integration models in education: Bridging research and practice. *Educational Technology Research and Development, 69*(4), 2187–2208. https://doi.org/10.1007/s11423-020-09911-0

Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2020). Enhancing pre-service teachers' Technological Pedagogical Content Knowledge (TPACK): A mixed-method study. *Educational Technology Research and Development*, *68*(1), 319–343. https://doi.org/10.1007/s11423-019-09692-1

Tupan, A. A., Marayate, M. R., Latuserimala, S., Leasa, M., & Batlolona, J. R. (2024). Worksheet based on project-based learning in science learning in elementary school. *Jurnal Penelitian dan Pengembangan Pendidikan*, *8*(3), 493–505. https://doi.org/10.23887/jppp.v8i3.79951

van Katwijk, L., Jansen, E., & Van Veen, K. (2023). Pre-service teacher research: A way to future-proof teachers? *European Journal of Teacher Education, 46*(3), 435–455. https://doi.org/10.1080/02619768.2021.1928070

van Nooijen, C. C. A., de Koning, B. B., Bramer, W. M., Isahakyan, A., Asoodar, M., Kok, E., van Merriënboer, J. J. G., & Paas, F. (2024). A cognitive load theory approach to understanding expert scaffolding of visual problem-solving tasks: A scoping review. *Educational Psychology Review, 36*(1), Article 20. https://doi.org/10.1007/s10648-024-09848-3

Velu, S., Wahid, I. S., & Tabianan, K. (2025). Stimulating innovative learning practices with tech: Artefacts influence learners' actions. *Journal of Innovation and Entrepreneurship, 14*(1), Article 42. https://doi.org/10.1186/s13731-025-00523-7

Wang, N., Cui, N., Xue, S., & Du, Q. (2026). The impacts of whole life cycle project management on the Sustainable Development Goals. *Journal of Asian Architecture and Building Engineering, 25*(3), 1–20. https://doi.org/10.1080/13467581.2025.2480750

Wasis, W., Sulaiman, R., Sudibyo, E., Yonata, B., & Prastiwi, M. S. (2018). The assessment model of undergraduate mathematics and science education competency based on Indonesian national qualification framework and 21st century demand. In *Proceedings of the Mathematics, Informatics, Science, and Education International Conference (MISEIC 2018)*. Atlantis Press. https://doi.org/10.2991/miseic-18.2018.29

Weidlich, J., & Kalz, M. (2026). How well does teacher education prepare for teaching with technology? A TPACK-based investigation at a university of education. *European Journal of Teacher Education*, *49*(1), 168–188. https://doi.org/10.1080/02619768.2023.2243645

Widodo, W., Sari, D. A. P., Martini, & Suyanto, T. (2019). Strengthening pre-service teachers' character: The application of ALLR learning model in basic science subject. In *Proceedings of the 1st International Conference on Education Social Sciences and Humanities (ICESSHum 2019)*. Atlantis Press. https://doi.org/10.2991/icesshum-19.2019.59

Yan, P., Zhu, Y., Wu, D., Wang, J., & Li, S. (2025). Exploring the pathway of project-based learning for enhancing core competency in educational psychology. *Journal of Education and Learning*, *14*(5), 357. https://doi.org/10.5539/jel.v14n5p357

Yusupova, M., Gazieva, S., Abdullayeva, Z., Umarova, Z., Akhmedova, M., &

Kambarova, M. (2025). Integrating project-based learning in English language teacher education for Sustainable Development Goals (SDGs). *International Journal of Language Education*, *1*(2), 245. https://doi.org/10.26858/ijole.v1i2.74938

Zhang, L., & Ma, Y. (2023). A study of the impact of project-based learning on student learning effects: A meta-analysis study. *Frontiers in Psychology*, *14*, 1202728. https://doi.org/10.3389/fpsyg.2023.1202728

***Gaguk Resbiantoro, S.Si., M.Pd. (Corresponding Author)**
Doctoral Program of Science Education,
Universitas Negeri Surabaya
Jl. Ketintang, Gayungan, Surabaya, East Java, 60231, Indonesia
Email: gaguk@uinsatu.ac.id

Prof. Dr. Wasis, M.Si.
Doctoral Program of Science Education,
Universitas Negeri Surabaya
Jl. Ketintang, Gayungan, Surabaya, East Java, 60231, Indonesia
Email: wasis@unesa.ac.id

Prof. Dr. Wahono Widodo, M.Si.
Doctoral Program of Science Education,
Universitas Negeri Surabaya
Jl. Ketintang, Gayungan, Surabaya, East Java, 60231, Indonesia
Email: wahonowidodo@unesa.ac.id