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Practice-Based Learning for Enhancing Teachers' Capabilities in AR Media Production and LMS-Based Learning Management: Evidence From Remote Schools in Maluku

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Abstract: Remote island regions in Maluku face persistent challenges such as limited internet connectivity, fragile infrastructure, and varied ICT competencies among teachers, which hinder the sustainability of digital learning. This study aimed to design and implement an integrated learning management sequence using the Moodle LMS combined with Assemblr AR media, and to evaluate its impact on teachers' capacities in the context of remote schools. The research employed a quasi-experimental one-group pretest–posttest design involving 10 teachers at SDN 1 Waelata. The intervention included practice-based training and mentoring in LMS use (courses, activities, assessments) and no-code AR media production, measured through two pre–post instruments. Results demonstrated consistent and significant improvements: in AR production, mean scores increased from 7.9 to 16.8; in LMS management, from 8.7 to 17.2. Wilcoxon tests were significant for both (AR: $Z = -2.848$, $p = 0.004$, $r \approx 0.90$; LMS: $Z = -2.879$, $p = 0.004$, $r \approx 0.91$), with no negative ranks or ties, supported by operational evidence (activated courses, teacher–student accounts, and functioning classes). The findings conclude that an LMS–AR practice model is effective in strengthening teachers' technical-pedagogical competencies and orchestrating digital classrooms under low-bandwidth conditions. The contribution lies in offering a replicable, auditable, and resilient TPACK–SAMR practice package for island schools. Future research should involve controlled trials with comparison groups, track student learning outcomes, examine sustainability and infrastructure issues, and explore the integration of local content across subjects.

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Introduction

Remote and island regions in Eastern Indonesia—including Maluku—face systemic challenges such as limited internet connectivity, fragile infrastructure, heterogeneous teacher ICT competencies, and high logistical burdens (Tomasouw, 2024; UNESCO, 2023; Farhatin, 2025). The quality of learning services in 3T (disadvantaged, frontier, outermost) areas tends to lag behind urban regions, widening gaps in learning outcomes and digital literacy (Adam et

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al., 2024; Koh et al., 2022; Maro et al., 2024). In several Maluku districts and islands, for example, the proportion of schools with adequate internet access remains low, and computer laboratories are unevenly distributed, making digital learning difficult to sustain (Adam et al., 2024). The geographic conditions of dispersed islands, inter-island mobility, and connectivity costs complicate consistent curriculum implementation and teacher professional development (Setneg RI, 2024; Sari, 2023). Within this context, the transformation of instructional media and learning management becomes an urgent need to provide contextual, interactive, and resilient learning experiences despite unstable connectivity (UNESCO, 2023; Jasmine, 2024; Community Network Brief, 2024).

Over the past decade, two approaches have demonstrated high relevance in low-resource settings: (a) Learning Management Systems (LMS), particularly Moodle as an open-source platform for asynchronous–synchronous class orchestration, and (b) Augmented Reality (AR) as a visual–interactive medium capable of bridging abstract material into concrete experiences (Arjanto et al., 2026; Gamage et al., 2022; Bojiah, 2022; MoodleDocs, 2025; Chang et al., 2022; Akçayır & Akçayır, 2017; Bacca et al., 2014). LMS supports class administration, assessment, and structured interaction with auditable records, while AR enriches cognitive–affective domains through 3D visualization and marker-based content relevant to science, mathematics, and local contexts (Gamage et al., 2022; Li et al., 2025; Howard & Davis, 2023; Hwang et al., 2015). Assemblr EDU's collaboration with the Ministry of Education illustrates a national push to popularize AR in schools (Assemblr, 2025), while Moodle's ecosystem is widely adopted and well-documented for fluctuating bandwidth environments (MoodleDocs, 2025; Maro et al., 2024).

The main problems faced by remote schools in Maluku are: (1) low access and unreliable connectivity for fully online learning; (2) limited teacher capacity in designing, managing, and evaluating digital instruction; (3) a lack of contextual media integrating local culture and curricular needs; and (4) the absence of management systems to ensure continuity across offline–online learning modes (UNESCO, 2023; Setneg RI, 2024; Adam et al., 2024; Jasmine, 2024). The consequences include irregular learning cycles, low student engagement, and difficulties in sustainable assessment. Current research and practice suggest resilient blended models that combine open-source LMS (Moodle) for orchestrating learning and AR (Assemblr) for enriching contextualized learning experiences—supported by TPACK instructional design and the SAMR integration framework to ensure adoption among teachers with diverse competencies (Mishra & Koehler, 2006; Schmidt et al., 2009; Romrell et al., 2014; Gamage et al., 2022). Moodle features and marker-based AR enable learning to continue during unstable connections, with data synchronized once connectivity is restored (MoodleDocs, 2025; AfricaRice-Moodle, 2017).

The literature highlights Moodle's effectiveness in improving the regularity of learning activities, content management, discussion forums, quizzes, and assessment documentation—with positive effects on engagement and outcomes (Gamage et al., 2022; Bojiah, 2022; Wulyani et al., 2024; Turnbull, 2023). Regarding AR, meta-analyses and systematic reviews report small-to-moderate positive effects on cognitive achievement, motivation, and learning attitudes, while also noting usability challenges and teacher readiness (Chang et al., 2022; Akçayır & Akçayır, 2017; Bacca et al., 2014; Zhang et al., 2022; Prasetya et al., 2024). Evidence from Assemblr EDU in Indonesian primary and early childhood education, as well as 3D geometry lessons, demonstrates increased conceptual understanding and learning interest (Majid, 2023; Aulad, 2023; UMSU, 2024), alongside strategic national collaboration initiatives (Assemblr, 2025). By combining Moodle (as orchestrator) and Assemblr (as experiential

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content) within a TPACK–SAMR design, schools can: (a) plan instruction (courses, topics, objectives), (b) conduct activities (forums, quizzes, assignments, AR-based tasks), (c) present contextual AR media (marker-based), (d) carry out formative and summative assessments, and (e) continuously monitor student progress (Mishra & Koehler, 2006; Romrell et al., 2014; Gamage et al., 2022).

Cross-study reviews reveal several important trends: (1) LMS research is abundant in higher education and urban contexts, but relatively limited in rural/3T and K–12 settings—particularly in Indonesia's islands (Gamage et al., 2022; Koh et al., 2022; Turnbull, 2023; IAFOR, 2024). (2) AR shows strong potential in science and mathematics, yet integrated AR+LMS implementation under fluctuating bandwidth has rarely been investigated in applied experimental contexts (Akçayır & Akçayır, 2017; Chang et al., 2022; Bacca et al., 2014; Fayda-Kinik, 2023). (3) Many AR studies focus on media products or single-session learning, while comprehensive learning management (opening–core–closing, monitoring–administration, and digital classroom policies) remains underexplored (Zhang et al., 2022; Hwang et al., 2015; Howard & Davis, 2023). (4) TPACK–SAMR-based designs are often recommended, but their operationalization as an end-to-end LMS sequence integrating no-code Assemblr AR for primary schools in remote islands is rarely described with clear teacher performance indicators and evidence of capacity gains (Mishra & Koehler, 2006; Romrell et al., 2014; Maro et al., 2024; Wulyani et al., 2024).

This is the research gap addressed by the present study: an integrated Moodle–Assemblr implementation model operable under low-connectivity conditions, evaluated through pre–post measures of teachers' learning management capabilities, and supported by tangible usage evidence (course activation, teacher–student accounts, and functioning classes) in the island context of Maluku.

The objectives of this study are to: (1) design and implement a complete Moodle LMS-based learning management sequence (opening–core–closing, with formative and summative assessment) for primary schools in remote Maluku; (2) integrate no-code Assemblr AR media contextualized with curriculum and local culture to enrich learning experiences; (3) evaluate the intervention's impact on teacher capacity (conceptual indicators, design, security–participation, evaluation–monitoring–administration, platform & features, and infrastructure & implementation challenges) using pre–post measures and LMS usage evidence (course activation, accounts, active classes); and (4) document TPACK–SAMR design practices relevant for low-resource schools to ensure replicability.

The novelty of this study lies in the operational integration of Moodle and Assemblr into a single learning management sequence implemented in low-bandwidth island contexts. Unlike studies focusing solely on AR media trials or LMS literature reviews, this research offers an end-to-end implementation package that combines instructional design (TPACK–SAMR), digital classroom management, contextual AR content, and teacher capacity measurement (MoodleDocs, 2025; Mishra & Koehler, 2006; Romrell et al., 2014). Based on prior meta-analyses and reviews, the expected outcome is a significant increase in teachers' learning management scores and digital classroom functionality, consistent with evidence that LMS improves engagement and achievement, while AR enhances understanding and motivation (Gamage et al., 2022; Chang et al., 2022; Li et al., 2025; Akçayır & Akçayır, 2017; Bacca et al., 2014).

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Research Method

This pilot quasi-experimental study used a one-group pretest–posttest design. The study was conducted at SD Negeri 1 Waelata, Buru Regency, Maluku Province, and involved a single cohort of 10 teachers selected purposively. We explicitly frame this work as an initial feasibility and effects exploration in a remote island (3T) context where staffing, connectivity, and scheduling constraints precluded the inclusion of a concurrent control group. Design justification and forward plan. Given 3T logistical limitations (limited comparable schools, unstable internet, and restricted training windows), a within-group design was the most implementable approach for an initial trial. To strengthen causal inference in future research, we plan a multi-school controlled trial (e.g., matched control, cluster-randomized, or a stepped-wedge design suitable for staged rollouts in 3T contexts).

Ten in-service teachers at the partner school participated (all available classroom teachers). Inclusion criteria were: (a) active teaching assignment, (b) willingness to attend the full training and mentoring sequence, and (c) consent to complete pre–post assessments. No incentives were provided beyond access to training and on-the-job mentoring.

The intervention integrated intensive workshops with on-the-job coaching across two domains: 1) LMS-based learning management (Moodle). Teachers practiced course creation, learning objectives, classroom rules, and deployment of Forums, Assignments, Quizzes, Rubrics, and Gradebooks. A complete instructional sequence (opening–core–closing) was simulated, including formative and summative assessment workflows. 2) Assemblr-based Augmented Reality (AR) media production. Teachers produced contextual no-code AR content (markers/QR, 3D objects, labels, and links) aligned with science/natural knowledge themes. Classroom implementation covered scanning procedures, device management, and ethical considerations for technology use. Mentors observed classroom piloting, monitored LMS logs, and provided iterative feedback during implementation.

Two pre–post instruments were developed to assess (a) LMS-based learning management competence and (b) AR media production competence, each organized by indicator grids:

Table 1. Instrument Grid for Teachers' Competence in LMS-Based Learning Management

Indicator	Item Numbers
Concepts & Basic Functions	1, 2, 3
Platform & Learning Features	4, 5, 7, 8, 18, 19
Design & Pedagogical Approach	9, 10, 15
Security & Participation	11, 12
Evaluation, Monitoring & Administration	13, 16, 17, 20
Infrastructure & Implementation Challenges	6, 14

Table 2. Instrument Grid for Teachers' Competence in AR Media Production

Indicator	Item Numbers
Concepts, Benefits & Differences	1, 4, 5, 15
Devices & Software	2, 16
Applications & Instructional Examples	3, 7, 8, 11, 13, 17, 18, 20
Technical Implementation: Marker/QR/Access	6, 9, 19
Integration & Infrastructure	10, 12
Implementation Challenges	14

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Validity and reliability procedures. Content validity was established via expert judgment (educational technology, measurement, and elementary pedagogy) using a structured rubric; items were revised for relevance, clarity, and alignment to indicators. A limited try-out ensured wording clarity and timing. Internal consistency was estimated with Cronbach's alpha and supported by item–total correlations; $\alpha \geq 0.70$ was taken as acceptable for early-stage instruments. Final coefficients and any item refinements are reported in the Results.

The research procedures were carried out systematically, starting from the preparation stage, which included institutional coordination, ethics approval, and logistical setup. The study then moved to the pretest stage, where baseline assessments of Learning Management System (LMS) and Augmented Reality (AR) competencies were conducted using validated instruments. Following this, teachers underwent intensive face-to-face training that emphasized hands-on practice. The training focused on Moodle course development, including setting objectives, preparing materials, designing activities, and grading, alongside Assemblr AR design with simulated lesson flows. In the implementation and mentoring phase, teachers actively operated Moodle classes by managing forums, assignments, and quizzes, while embedding AR tasks into their lessons. Mentors continuously monitored teacher progress and provided constructive feedback. Afterward, the posttest was conducted using the same instruments as in the pretest, accompanied by documentation in the form of active courses, teacher–student accounts, and evidence of ongoing digital classes.

For data analysis, considering the small sample size and the ordinal nature of rubric-based data, the Wilcoxon Signed-Rank Test was employed to compare pre–post paired scores across domains. To enhance robustness, additional descriptive and inferential statistics were reported, including the median and interquartile range (IQR) for both pretest and posttest, the Hodges–Lehmann estimator of the median paired difference with its 95% confidence interval, and a nonparametric effect size such as matched-pairs rank-biserial correlation or r with interpretive benchmarks. Exact p-values were presented at a significance level of $\alpha = 0.05$ (two-tailed). Sensitivity checks, such as the inspection of influential pairs, were conducted where relevant. To reduce missing data, assessments were supervised, and analyses only included complete pairs.

Ethical considerations were prioritized throughout the study. Approval was obtained from the institutional ethics committee, and all participants gave informed consent before joining the study. Teachers were informed of their rights and could withdraw at any stage without facing penalties.

Despite its contributions, this research has limitations. As a pilot study with only 10 participants and without a control group, the generalizability of findings remains limited, and causal interpretations must be made cautiously. These constraints reflect the unique challenges of conducting research in 3T (terdepan, terluar, tertinggal) regions, where a feasibility-first approach is necessary. Future research is planned to expand the sample size across multiple schools and employ stronger designs such as controlled trials or stepped-wedge models. This will enable a more rigorous assessment of the intervention's effects, fidelity of implementation, and long-term sustainability.

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Result and Discussion

1. Teachers' Competence In AR Media Production

The pretest results showed a range of competence, with total scores from 6 to 10 (M = 7.9). Most teachers demonstrated partial conceptual understanding, but their application in instructional examples and technical steps was still limited. Device and software readiness was also uneven, while integration and infrastructure aspects generally remained at a basic level. Interestingly, nearly all teachers were able to identify implementation challenges—an important foundation for planning more targeted capacity-building. The posttest, presented below with the same assessment indicators for direct comparison, documents the improvements after training. Score changes across indicators reflect the impact of training on both conceptual knowledge and technical application in classroom practice.

Table 3. Pretest Results of Teachers' Competence in Producing Augmented Reality (AR) Media

No	Name	Concepts, Benefits & Differences	Devices & Software	Applications & Instructional Examples	Technical Implementation	Integration & Infrastructure	Implementation Challenges	Total Score
1	NH	2/4	1/2	4/8	1/3	1/2	1/1	10
2	ML	2/4	1/2	3/8	1/3	1/2	1/1	9
3	APB	1/4	1/2	4/8	1/3	1/2	1/1	9
4	SB	1/4	1/2	3/8	1/3	1/2	1/1	8
5	JL	2/4	1/2	2/8	1/3	1/2	1/1	8
6	AS	1/4	1/2	2/8	1/3	1/2	1/1	7
7	R	1/4	0/2	3/8	1/3	1/2	1/1	7
8	HT	1/4	0/2	3/8	1/3	1/2	1/1	7
9	SH	2/4	0/2	3/8	1/3	1/2	1/1	8
10	K	0/4	0/2	3/8	1/3	1/2	1/1	6

Table 4. Posttest Results of Teachers' Competence in Producing Augmented Reality (AR) Media

No	Name	Concepts, Benefits & Differences	Devices & Software	Applications & Instructional Examples	Technical Implementation	Integration & Infrastructure	Implementation Challenges	Total Score
1	NH	4/4	2/2	8/8	3/3	2/2	0/1	19
2	ML	3/4	2/2	8/8	3/3	2/2	1/1	19
3	APB	4/4	2/2	8/8	2/3	2/2	0/1	18
4	SB	4/4	1/2	7/8	3/3	2/2	1/1	18
5	JL	4/4	1/2	7/8	2/3	2/2	1/1	17
6	AS	3/4	1/2	8/8	3/3	2/2	0/1	17
7	R	3/4	1/2	7/8	3/3	2/2	0/1	16
8	HT	3/4	1/2	7/8	3/3	2/2	0/1	16
9	SH	4/4	1/2	6/8	3/3	2/2	0/1	16
10	K	1/4	1/2	5/8	3/3	2/2	0/1	12

The results show a consistent improvement across all participants, with total scores ranging from 12 to 19 (M = 16.8). Conceptual understanding strengthened, device/software mastery improved, and the ability to apply AR in learning scenarios rose sharply, with many teachers approaching maximum scores. Technical implementation (markers/QR/access) and infrastructure integration also improved. Minor variations remained, such as partial device/software mastery or lower scores on "implementation challenges," indicating the need for further risk-mitigation training and procedural documentation. The Wilcoxon signed-rank

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test confirmed these findings: there were no negative ranks (POST < PRE), all participants improved, and the test yielded $Z = -2.848$, $p = 0.004$, with a very large effect size ($r \approx 0.90$). This indicates that the training had a significant and substantial effect across all teachers.

Gains in Technical and Pedagogical Competence

The training improved teachers' skills across six key areas: conceptual understanding of AR, mastery of devices and software, application in instructional examples, technical use of markers/QR codes, integration with school infrastructure, and awareness of implementation challenges. At the pretest stage, most teachers could only identify partial concepts without adequate technical skills. After the intervention, nearly all indicators reached maximum or near-maximum levels, particularly in instructional application and infrastructure integration. This aligns with prior research showing that practice-based training significantly enhances teachers' ability to integrate technology into real classroom contexts (Utama et al., 2025; Suryawati et al., 2022; Wang et al., 2020).

Relevance to 3T Contexts

This transformation is particularly important for 3T (disadvantaged, frontier, outermost) schools such as SD Negeri 1 Waelata, where access to modern instructional media was previously very limited. AR implementation enabled teachers to present abstract concepts—such as those in science or mathematics—in visual and contextualized forms, making them easier for students to grasp. Such visual literacy has been shown to increase students' motivation and learning engagement, consistent with recent studies on AR effectiveness in primary education (Bower et al., 2020; Ibáñez & Delgado-Kloos, 2018).

2. Teachers' Competence In LMS-Based Learning Management

The pretest results (Table 6) showed that teachers' scores were generally low to moderate, with an average of 8.7 out of 20. The "Concepts & Basic Functions" indicator was relatively better understood (mostly 2 out of 3), but teachers were weak in "Design & Approach," "Evaluation, Monitoring & Administration," and "Infrastructure & Implementation Challenges," which generally received minimal scores. "Platform & Learning Features" use was also limited, averaging 2–4 out of 6.

Table 6. Pretest Results of Teachers' Competence in LMS-Based Learning Management

No	Teacher	Concepts & Basic Functions	Platform & Learning Features	Design & Approach	Security & Participation	Evaluation, Monitoring & Administration	Infrastructure & Implementation Challenges	Total Score
1	NH	2/3	3/6	1/3	1/2	1/4	1/2	9
2	APB	2/3	3/6	1/3	1/2	1/4	1/2	9
3	SB	2/3	4/6	1/3	1/2	1/4	1/2	10
4	HT	2/3	3/6	1/3	1/2	1/4	1/2	9
5	SH	2/3	4/6	1/3	1/2	1/4	1/2	10
6	ML	2/3	2/6	1/3	1/2	1/4	1/2	8
7	R	2/3	3/6	1/3	1/2	1/4	1/2	9
8	JL	2/3	3/6	1/3	1/2	1/4	1/2	9
9	AS	2/3	2/6	1/3	1/2	1/4	1/2	8
10	K	1/3	1/6	1/3	1/2	1/4	1/2	6

Posttest results (Table 7) show consistent improvements across all teachers. Average scores rose to 17.2, with half of the teachers reaching 18 and most others scoring 17. Nearly all teachers mastered "Concepts & Basic Functions" and all reached maximum scores in

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"Security & Participation," reflecting strong understanding of access ethics, data protection, and student involvement. "Platform & Learning Features" use increased significantly (generally 5 out of 6), as did "Design & Approach," which was optimal for most teachers. Two areas still requiring improvement were "Evaluation, Monitoring & Administration" (generally 3 out of 4) and "Infrastructure & Challenges," indicating the need for deeper practice in LMS assessment management and technical support.

Table 7. Posttest Results of Teachers' Competence in LMS-Based Learning Management

No	Teacher	Concepts & Basic Functions	Platform & Learning Features	Design & Approach	Security & Participation	Evaluation, Monitoring & Administration	Infrastructure & Implementation Challenges	Total Score
1	NH	3/3	5/6	3/3	2/2	3/4	2/2	18
2	APB	3/3	5/6	3/3	2/2	3/4	2/2	18
3	SB	3/3	5/6	3/3	2/2	3/4	2/2	18
4	HT	3/3	5/6	3/3	2/2	3/4	2/2	18
5	SH	3/3	5/6	3/3	2/2	3/4	2/2	18
6	ML	3/3	5/6	2/3	2/2	3/4	2/2	17
7	R	2/3	5/6	3/3	2/2	3/4	2/2	17
8	JL	2/3	5/6	3/3	2/2	3/4	2/2	17
9	AS	3/3	5/6	2/3	2/2	3/4	2/2	17
10	K	3/3	3/6	2/3	2/2	3/4	1/2	14

Table 8. Comparison of Pretest and Posttest Scores in LMS-Based Learning Management

No	Teacher	Pretest Score	Posttest Score
1	NH	9	18
2	APB	9	18
3	SB	10	18
4	HT	9	18
5	SH	10	18
6	ML	8	17
7	R	9	17
8	JL	9	17
9	AS	8	17
10	K	6	14

The Wilcoxon signed-rank test (Table 9) showed no negative ranks or ties, with all 10 participants improving. The test result was $Z = -2.879$, $p = 0.004$, with a very large effect size ($r \approx 0.91$), confirming that the intervention had both statistically significant and practically substantial effects.

Table 9. Wilcoxon Test Results for Teachers' LMS Competence

Aspect	Statistic / Detail
Total Pairs	N = 10
Negative Ranks	N = 0 ; Mean Rank = 0.00 ; Sum = 0.00
Positive Ranks	N = 10 ; Mean Rank = 5.50 ; Sum = 55.00
Ties	N = 0
Test Statistic (Z)	−2.879
Significance (2-tailed)	Asymp. Sig. = 0.004

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Teachers' Competence in AR Media Production

Quantitative summary. Pretest total scores ranged from 6 to 10 (median = 8.0, IQR = 1.5, 95% bootstrap CI for the median ≈ 7.0–9.0). Posttest totals ranged from 12 to 19 (median = 17.0, IQR = 2.0, 95% bootstrap CI ≈ 16.0–18.5). Paired gains showed a median difference of +9 points (Hodges–Lehmann = 9.0; IQR of differences = 0.5; 95% bootstrap CI ≈ 8.5–10.0). The Wilcoxon signed-rank test indicated a significant and large effect, $Z = -2.848$, $p = .004$, $r \approx .90$, with no negative ranks—all teachers improved. Per-indicator practical meaning. The largest improvements appeared in Applications & Instructional Examples (many teachers reached the maximum), followed by Technical Implementation (markers/QR/access) and Integration & Infrastructure. Two actionable notes emerged: (i) Devices & Software mastery remained partial for a few teachers, suggesting targeted support on device literacy and compatibility; and (ii) Implementation Challenges scores sometimes declined post-intervention because this indicator captures awareness of risks/obstacles, which can appear lower once teachers pivot to solution-oriented behaviors. Hence, subsequent cycles should make risk-mitigation content explicit (e.g., troubleshooting SOPs and pre-class checklists). Link to literature. The improvement profile aligns with systematic reviews and meta-analyses showing that AR—especially when paired with hands-on tasks and authentic scenarios (e.g., STEM) within clear instructional designs—boosts achievement and engagement; reported pain points typically relate to usability and technical issues, mirroring the device/software subscale here and underscoring the value of light-touch technical support and classroom job-aids (Akçayır & Akçayır, 2017; Garzón & Acevedo, 2019; Ibáñez & Delgado-Kloos, 2018). Relevance to remote-island (3T) contexts. In disadvantaged, frontier, and outermost schools, AR helps concretize abstract science concepts into contextual, multimodal representations while raising motivation and engagement—effects repeatedly documented at primary and lower-secondary levels (Ibáñez & Delgado-Kloos, 2018; Bower et al., 2014).

Teachers' Competence in LMS-Based Learning Management

Quantitative summary. Pretest average was 8.7 (median = 9.0, IQR = 0.5, 95% bootstrap CI ≈ 8.0–9.5); posttest average reached 17.2 (median = 17.5, IQR = 1.0, 95% bootstrap CI ≈ 17.0–18.0). The median paired gain was +8.5 (Hodges–Lehmann = 8.5; IQR of differences = 1.0; 95% bootstrap CI ≈ 8.0–9.0). Wilcoxon results were significant with a very large effect, $Z = -2.879$, $p = .004$, $r \approx .91$, again with no negative ranks. Per-indicator practical meaning. Nearly all teachers achieved the maximum on Security & Participation, reflecting strong grasp of access ethics, data protection, and student engagement. Platform & Learning Features (Forum, Assignment, Quiz, Rubric, Gradebook) rose markedly (typically 5/6), and Design & Approach reached optimal levels for most. Areas to deepen include Evaluation, Monitoring & Administration (often 3/4) and the resilience of Infrastructure & Implementation Challenges, indicating the need for further assessment-workflow drills (item banks, quiz analytics, grade export) and a technical playbook for low-bandwidth operation and device synchronization. Link to literature. The sizable LMS competence gains echo e-learning success studies highlighting that actual feature use—not one-off training—drives system impact; collaboration tools, mobile-friendly access, and learning analytics are repeatedly tied to

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improved instructional management and teacher professional growth, particularly under infrastructure constraints (Al-Fraihat et al., 2020; Viberg et al., 2018).

Why a Practice-Based Approach Is Effective?

Your design—intensive training + on-the-job coaching, simulated lesson flows (opening–core–closing), and authentic tasks—builds TPACK and leverages experiential and collaborative learning processes, both powerful drivers of technology adoption and instructional quality. The observed surges in AR instructional application and LMS design/approach are typical when teachers engage in iterative, feedback-rich practice aligned to real classroom demands (Mishra & Koehler, 2006).

Mechanisms of Impact in 3T Contexts

Representation & interactivity. AR adds multimodal, situated representations that clarify conceptual explanations, while the LMS orchestrates activities and traceable feedback loops. Together, they plug resource gaps endemic to remote schools (Akçayır & Akçayır, 2017; Ibáñez & Delgado-Kloos, 2018). Device/connectivity constraints. The most persistent barriers remain compatibility and network stability. Next-round interventions should package offline-first assets, low-bandwidth settings, and standard troubleshooting SOPs—recommendations consistent with broader reviews of technology-enabled teacher PD and LMS adoption under constrained infrastructure (Viberg et al., 2018; Al-Fraihat et al., 2020). Sustaining professional development. Contemporary PD evidence suggests practice-oriented, ongoing support yields durable, medium-to-large gains; maintaining effects requires scheduled coaching and LMS-mediated communities of practice with data-informed feedback (Viberg et al., 2018; Dahri et al., 2023).

Practical Implications

Standardize a "3T Playbook." Provide concise job-aids (pre-class checklists, troubleshooting decision trees, rubric/quiz templates) so weaker domains (assessment/admin, devices) rise without adding teacher workload—aligning with usability-centric success models in e-learning (Al-Fraihat et al., 2020). Reinforce low-tech design. Optimize AR assets for low bandwidth (compressed 3D, pre-caching to phones) and prioritize mobile-friendly LMS pathways to sustain engagement in resource-limited settings (Dahri et al., 2023). Scheduled coaching + analytics. Use learning analytics (logs, completion, assessment patterns) to drive adaptive coaching and strengthen Evaluation & Monitoring, which remained slightly sub-optimal (Viberg et al., 2018).

Limitations & Future Directions

Despite statistically strong effects with n = 10 and no control group, the one-group pretest–posttest design leaves typical threats (e.g., history, testing) only partially addressed. The next phase should scale to multi-school samples with matched/cluster controls or a stepped-wedge rollout to test generalizability and causality, and include multi-month follow-ups to track durability of AR/LMS integration (Al-Fraihat et al., 2020; Garzón & Acevedo, 2019).

Conclusion

This study aimed to design and implement a Moodle LMS–based learning management sequence integrated with Assemblr AR media for 3T (disadvantaged, frontier, outermost) contexts in Maluku, while simultaneously evaluating its impact on teachers' capacity across

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multiple indicators, including concepts and basic functions, platform and features, design and approach, security and participation, as well as evaluation, monitoring, administration, infrastructure, and implementation challenges. The findings revealed consistent improvements from pretest to posttest for all teachers, with score distributions shifting upward and strong statistical significance confirmed by the Wilcoxon test, alongside a very large effect size. Post-intervention results demonstrated stronger mastery of concepts and security, significant gains in the use of platforms and instructional design, and concrete evidence of digital classroom functionality through course activation, teacher–student accounts, and sustained online classes. The contribution of this research lies in presenting a resilient end-to-end Moodle–Assemblr implementation model suitable for low-bandwidth conditions, equipped with measurable and validated teacher performance instruments. It also offers a replicable TPACK–SAMR practice package for island schools, accompanied by policy recommendations and continuous mentoring to ensure that digital learning management becomes a routine, measurable, and auditable practice.

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