

Transforming the Ethnochemistry Technology Lecture Model: Integrating Digital Literacy and Character Education

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Abstract: Papua, Indonesia, has a rich ethnochemical heritage, including plant-based dyeing and starch processing, that is rarely represented in tertiary chemistry curricula. At the same time, uneven internet connectivity constrains students' opportunities to develop robust digital literacy. These dual challenges highlight a need for e-learning models that are culturally grounded, technologically adaptive, and pedagogically transformative. This study redesigned an Ethnochemistry Technology lecture into a low-bandwidth, culturally embedded, and virtue-infused e-learning model to improve students' digital literacy and character outcomes measurably. Using a semester-long Design-Based Research approach at a public university in Jayapura, the course integrated Papuan case vignettes, flipped and HyFlex delivery, downloadable H5P interactives, short micro-lectures, an augmented-reality dye-extraction lab with offline alternatives, communal reflection journals, peer mentoring, and a service-learning partnership with a village craft cooperative. Cultural consultants, including community elders and a dye artisan, ensured epistemic authenticity. Learning tasks were aligned with Kurikulum Merdeka virtues, respect for local wisdom, collaboration, and environmental stewardship, and mapped to UNESCO digital-literacy domains. Findings indicate substantial and educationally meaningful gains in digital literacy and character mastery. Students demonstrated great improvement across all digital-literacy domains, alongside marked increases in demonstrated respect for local wisdom, collaborative engagement, and environmental responsibility. Engagement indicators also rose consistently throughout the semester, particularly during immersive and community-linked activities. Qualitative feedback revealed heightened confidence in evaluating digital sources and a deeper recognition of chemistry within local cultural practices. Beyond local impact, this study contributes to e-learning practice by presenting a scalable blueprint for culturally responsive, low-bandwidth digital pedagogy in resource-constrained contexts. It advances the field of e-learning in Papua by validating indigenous knowledge as a central epistemic resource in technology-enhanced higher education. The model demonstrates that digital transformation need not marginalize local culture; instead, it can amplify it. Future research should explore multi-campus replication, long-term retention effects, and adaptation for additional Indigenous language communities.

Keywords: Ethnochemistry, Digital literacy, Character education, Flipped learning, Design-based research

1. Introduction

Authors in Indonesia repeatedly note that integration of local wisdom into chemistry curricula, learning tools, and teaching materials remains rare, creating a persistent implementation gap despite strong conceptual justification. Ethnochemistry research consistently argues that chemistry instruction becomes more meaningful when chemical concepts are grounded in learners' lived cultural contexts and "home-cultures," thereby improving engagement and conceptual accessibility (Irfandi, 2022). This gap is also documented in Indonesia, where ethnochemistry is positioned as a means to legitimize indigenous cultural knowledge within formal chemistry education and to connect classroom chemistry to culturally situated practices (Wahyudiati and Qurniati, 2023).

Within the existing ethnochemistry literature, "digital mediation" has mainly been operationalized as technology-based learning media rather than as a systematically engineered lecture model that simultaneously measures digital literacy competencies and character outcomes. Nevertheless, multiple studies demonstrate that ethnochemistry content can be embedded in web-based or multimedia formats, such as Weebly-based websites (Irnawati and Rahmawan, 2024), and microblog-based learning resources (Anggreni, Hadiarti and Fadhilah, 2023). These studies collectively provide evidence that ethnochemistry can be designed for digitally mediated delivery. Still, they do not, as a body, establish an integrated higher-education lecture architecture that jointly targets (i) digital literacy as an explicit competence, (ii) indigenous epistemic legitimacy, and (iii) measurable character outcomes, reinforcing the fragmentation highlighted in the task (Leny Heliawati *et al.*, 2022). Incorporating Papua's ethnochemical heritage into STEM education and addressing digital literacy gaps offer significant opportunities to enhance the relevance and effectiveness of education in the region.

Furthermore, aligning educational practices with character education mandates can ensure that students emerge as informed, responsible, and culturally aware individuals who can contribute positively to their communities.

Current ethnochemistry technology courses at the host public university in Jayapura still follow a teacher-centred slide-and-chalk routine. Formative evaluations in 2024 revealed that fewer than 40 % of students could (i) describe a locally sourced dye-extraction pathway or (ii) pass a basic digital-information verification task. Moreover, observational rubrics found limited evidence of the Merdeka virtues during laboratory teamwork.

1.1 Research Question

Against this background, this study asks the following questions:

RQ1: How can a culturally grounded, digitally mediated lecture model be engineered to lift students' digital-literacy competencies while legitimising Papuan ethnochemistry?

RQ2: To what extent does that model foster measurable growth in the targeted character values of respect, collaboration, and environmental stewardship?

The remainder of this article proceeds as follows. Section 2 synthesises literature on ethnochemistry pedagogy, technology-enhanced lecture models, digital-literacy frameworks for developing regions, and character-education theory, culminating in a visual conceptual model. Section 3 details the Papuan context and needs analysis that informed the design specification. Section 4 outlines the mixed-methods Design-Based Research protocol, instruments, and ethical safeguards. Section 5 documents the iterative development of the Transformative Ethnochemistry Lecture Model, including interactive H5P content and augmented-reality dye labs co-facilitated by community elders. Section 6 reports quantitative and qualitative results; Section 7 interprets those findings in light of prior work and identifies limitations. Section 8 concludes with practical recommendations and directions for multi-campus replication.

By foregrounding ethnochemical heritage, scaffolding digital literacies, and embedding *Merdeka*-aligned virtues in every task, the proposed model seeks to demonstrate that chemistry education in Papua can be simultaneously scientific, digital, and deeply human.

2. Literature Review

2.1 Ethnochemistry in Tertiary Chemistry Education

Ethnochemistry, as a subfield of ethnoscience, is commonly defined as culturally specific knowledge and practices that can be interpreted through chemistry concepts (i.e., “specific cultural behavior related to chemistry”) and therefore can function as a legitimate learning source rather than mere anecdote (Leny Heliawati *et al.*, 2022). Empirical studies in Indonesia largely operationalize ethnochemistry by identifying, inventorying, and mapping local traditions to chemistry topics (e.g., aligning cultural practices with atomic-structure content), indicating its potential to contextualize abstract theory through culturally familiar phenomena (Irawati *et al.*, 2023). Although many implementations are reported in school-oriented settings, they explicitly argue for curriculum-level integration of indigenous knowledge to support scientific literacy and innovation tied to regional cultural identity, rationales that are directly transferable to tertiary chemistry programs (Leny Heliawati *et al.*, 2022).

In regions like Papua, where knowledge of traditional practices such as sago fermentation is rich yet underrepresented in academic curricula, there is an acute need to redesign educational models that do not compromise scientific rigor (S. Rahmawati *et al.*, 2025). One promising approach involves intertwining ethnochemistry with modern scientific teaching methods, thereby creating a curriculum that not only deconstructs indigenous knowledge but also reconstructs it within a scientific framework. This would empower students as custodians of their cultural heritage while promoting scientific literacy (Smith, Avraamidou and Adams, 2022). Implementing education models that support cultural sustainability will be crucial in bridging existing gaps between traditional knowledge and modern scientific methodologies (Yanti *et al.*, 2025a). Ultimately, integrating ethnochemical principles into tertiary chemistry education in Indonesia offers a dual opportunity: fostering deeper engagement with chemistry through cultural relevance. It enhances chemical literacy through innovative pedagogical strategies. This approach not only helps preserve indigenous knowledge but also prepares students to navigate and contribute meaningfully to modern scientific landscapes (Torres, Mouro and Mesquita, 2024).

2.2 Technology-Enhanced Lecture Models

Technology-enhanced lecture models in higher-education science are framed as ICT-enhanced teaching that leverages LMS, mobile devices, and virtual/online tools for flexible, blended, and distance learning rather than simple digitization of lectures (Asli, Basheer and Hugerat, 2023). Design-oriented frameworks emphasize structuring online learning for inquiry and discourse (e.g., Community of Inquiry) (Redfors *et al.*, 2022) and recognizing that “mobile learning” outcomes depend on integrated device, learner social dimensions, not tools alone (Sezen-Barrie *et al.*, 2023). Empirical implementations often operationalize enhancement through scalable interactivity (e.g., rapid response/feedback, and peer learning), which is associated with improved conceptual and quantitative problem-solving compared with traditional lecturing (Whipple *et al.*, 2021). However, syntheses caution that educational technology adoption can remain under-theorized (e.g., documented theoretical gaps in gamification research), thereby limiting epistemic transformation (Tok, 2025). In parallel, culturally responsive, dialogic, technology-enabled curricula and culturally sustaining STEM pedagogy argue that digital mediation should be designed to sustain learners’ cultures and address power/identity, not merely deliver content (Parsons *et al.*, 2023). Anti-racist science education further warns that culture-based frameworks require substantive curriculum shifts rather than “buzzwords” (Mshayisa, 2020).

2.3 Digital-literacy Frameworks for Developing Regions

In developing regions such as Indonesia, digital literacy frameworks are crucial for enhancing educational quality and equity, particularly in underrepresented areas like West Papua. Three noteworthy frameworks can significantly impact these initiatives. Digital literacy (often framed as digital competence) is commonly operationalized through international reference frameworks such as the European DigComp and UNESCO’s Digital Literacy Global Framework (DLGF), which specify assessable components for education and training initiatives (Heaney, 2025). DigComp delineates competence across information/data literacy (supporting cognitive evaluation), communication/collaboration, digital content creation (technical production), safety (socio-ethical participation), and problem solving, and it includes knowledge, skills, and attitudes (Çebi and Reisoğlu, 2020). Reviews in higher education further show that digital literacy research clusters around measuring levels, identifying influencing factors, relating competence to achievement, and using pedagogical approaches, supporting the need for contextualized evaluation rubrics and frameworks across settings (Rosli *et al.*, 2023). Importantly, educator/learner digital-competence needs are reported to vary with local conditions and region-specific constraints, implying that “developing region” implementations require adaptation rather than direct transplantation of global standards (Schumann, Lehmann and Peters, 2025). However, these mainstream frameworks do not explicitly foreground epistemic sensitivity to indigenous knowledge systems, suggesting a conceptual gap when digital literacy is intended to support knowledge pluralism in culturally diverse contexts (Heaney, 2025).

2.4 Character Education Theories

Character education is critical to students’ moral and civic development, and several theories and frameworks guide its implementation in educational systems. In Indonesia, the *Kurikulum Merdeka* operationalizes Lickona’s principles by outlining six core virtues: faith, global citizenship, independence, critical-creative thinking, collaboration, and environmental stewardship (Sitanggang *et al.*, 2025). This curriculum mandates integrating these virtues across all disciplines, ensuring that character education is not siloed but an integral component of the educational experience. Research supports the idea that character education fosters social competencies and emotional attachments to moral values. Sitanggang *et al.* (2025) conducted a systematic review that highlights the varying cultural contexts in character education, emphasizing the integration of local values and digital literacy, thereby further enriching the educational experience for students (Lewis *et al.*, 2024). This integration encourages empathy and a civic-minded approach to learning. Moreover, the implementation of interactive teaching strategies enhances the effectiveness of character education by fostering dialogue and engagement among students, enabling them to internalize moral and civic values actively (Maloney *et al.*, 2022).

Furthermore, the role of culturally responsive teaching intertwined with character education is significant. By integrating local cultural contexts, such as Papua culture or local wisdom, into character education frameworks, educators can enhance the relevance and applicability of character values in students’ lives (Suswandari, 2017). This approach promotes a connection to heritage and nurtures a sense of identity and belonging, which is essential for the development of robust civic characters.

2.5 Synthesised Conceptual Model

The integration of indigenous knowledge into modern pedagogy requires a framework that honours cultural heritage while leveraging contemporary educational innovations. The Transformative Ethnochemistry Lecture Model positions Papuan ethnochemistry at the centre of a dynamic, multi-layered learning ecosystem. By embedding traditional chemical knowledge and artifacts into technology-supported instruction, the model creates culturally relevant learning experiences while simultaneously cultivating 21st-century competencies. It theorises that sustainable improvement in student learning outcomes arises not from isolated strategies, but from the interplay between content, process, skills, and values, iteratively refined through Design-Based Research (DBR).

The model further highlights the reciprocal reinforcement between these systems: digital tools amplify the visibility of ethnochemistry, indigenous cases contextualise digital practices, and character education shapes the ethical and collaborative use of technology. Collectively, this synthesised conceptual model offers a pathway for culturally responsive, technology-mediated education that advances both digital literacy and character formation, while safeguarding indigenous chemical heritage, as in Figure 1.

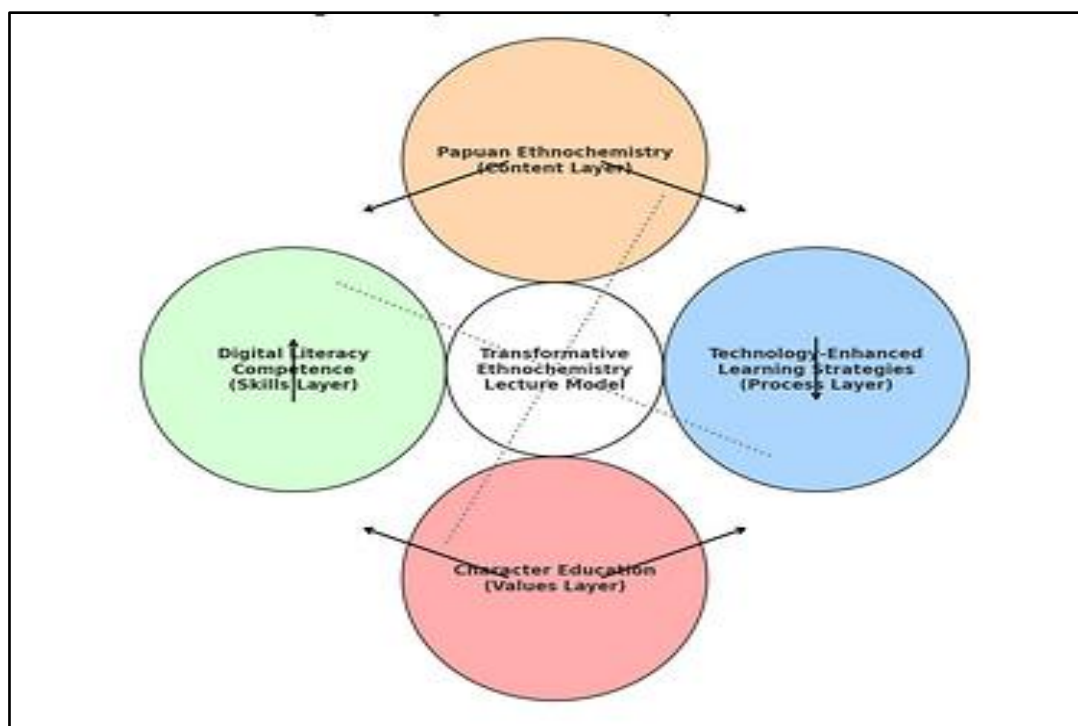


Figure 1: Conceptual Model

Figure 1 shows the four layers, the Transformative Ethnochemistry Lecture Model at the centre, cyclic DBR arrows, and dotted reciprocal reinforcement lines. It is a conceptual illustration of the "Transformative Ethnochemistry Lecture Model" at the intersection of four layers: content, Papuan ethnochemistry; process; technology-enhanced learning strategies; and skills, digital literacy competence, and values, character education. Arrows indicate cyclic DBR iterations, while dotted lines show reciprocal reinforcement between layers.

3. Methods

3.1 Research Design

Design-Based Research (DBR) is a methodological approach that integrates the design and study of educational interventions in real-world settings. It is characterized by iterative cycles of analysis, design, development, implementation, and evaluation that allow refinement of both the intervention and the underlying design principles. This approach is efficient in creating validated educational products and transferable design principles, as demonstrated in various studies across different educational contexts. The analysis phase involves identifying the problem and understanding the context. For instance, in the study of mobile social media tools

for heutagogical learning, the analysis phase helped in establishing draft design principles in collaboration with teachers and literature (Narayan, Herrington and Cochrane, 2019).

Design-based research (DBR) enables quick adjustments to interventions based on real-time feedback, as seen in studiesf technology integration courses, where community of practice models were iteratively refined (Sadik, 2021). DBR's iterative nature leads to the development of robust educational tools, such as mobile virtual reality learning environments designed to enhance learner-centered pedagogies (Cochrane *et al.*, 2017). DBR generates principles that can be adapted to similar contexts, as demonstrated in the study of online instructor training, which identified principles applicable to other online education settings (Shattuck and Anderson, 2013).

3.2 Sampling Techniques

The purposive sampling strategy described in the study aligns with the instructional intervention by ensuring that all participants, including students, lecturers, and community partners, are integral to the learning environment. This approach enhances ecological validity by embedding the intervention within a naturally occurring classroom setting, thus facilitating a comprehensive educational experience that integrates academic, technological, and cultural dimensions. Selecting participants based on their roles and expertise ensures the learning model is both inclusive and representative of the diverse knowledge systems involved.

The purposive sampling strategy effectively integrates academic and cultural dimensions by involving community partners recognized for their cultural authority and expertise in traditional practices. This aligns with the concept of knowledge coevolution, which emphasizes integrating Western and Indigenous knowledge systems to create mutually beneficial new knowledge (Chapman and Schott, 2020). The involvement of lecturers with ongoing teaching responsibilities ensures that the academic component of the course is robust and aligned with the instructional goals. This is similar to the approach in food-systems education, where collective agency is scaffolded across curricula to enhance learning outcomes (Jordan *et al.*, 2023).

The study was conducted at a public university in Jayapura, Papua, Indonesia, within the instructional context of the Ethnochemistry Technology course. Participants comprised three distinct groups representing both academic and community-based perspectives. The primary group consisted of 120 students in second-year chemistry majors (68% female; mean age = 20.7 years) who were officially enrolled in the course. Instruction was facilitated by four faculty members who regularly co-taught the subject and contributed expertise in chemistry education and digital pedagogy. In addition, three community partners, two respected village elders, and one local craft-dye artisan were engaged as cultural consultants to provide authentic ethnochemical cases and artifacts. Their participation ensured that the course design was grounded in local traditions while bridging academic and indigenous knowledge systems.

3.3 Intervention Phases and Learning Environment

The intervention was structured around a five-phase design-based research (DBR) cycle, integrating both pedagogical and technological innovations within a culturally grounded learning environment. Each phase was carefully sequenced to ensure alignment between needs assessment, collaborative design, digital resource development, classroom implementation, and rigorous evaluation. The learning environment combined HyFlex delivery with contextually responsive tools and strategies to accommodate diverse student needs, including those with limited internet bandwidth. Table 1 outlines the phases, weeks, key activities, and the researcher's role.

Table 1: Intervention Phases and Learning Environment

Phase	Weeks	Key Activities	Researcher Role
Analyse	1-3	Needs analysis, baseline surveys, syllabus audit	Collect data; map gaps
Design	4-5	Co-design workshops with lecturers & elders; storyboard flipped materials; align tasks to UNESCO-DLGF and <i>Merdeka</i> virtues	Facilitate; document decisions.
Develop	6-8	Produce low-bandwidth H5P interactives, AR dye-lab app (Blippar), and character-reflection journals; pilot usability tests.	Build & iterate
Implement	9-14	HyFlex delivery: asynchronous pre-class videos + in-class problem-based sessions + field trip to local dye site; live data capture via LMS	Observe; provide tech support.
Evaluate	15-16	Post-tests, focus groups, lecturer reflections, and member-checking with elders	Analyse; validate findings

The intervention not only addressed technological and pedagogical dimensions but also cultivated a culturally sustaining learning environment, adaptable to bandwidth constraints and responsive to local values, as shown in the flowchart-style diagram of the intervention phases in Figure 2.

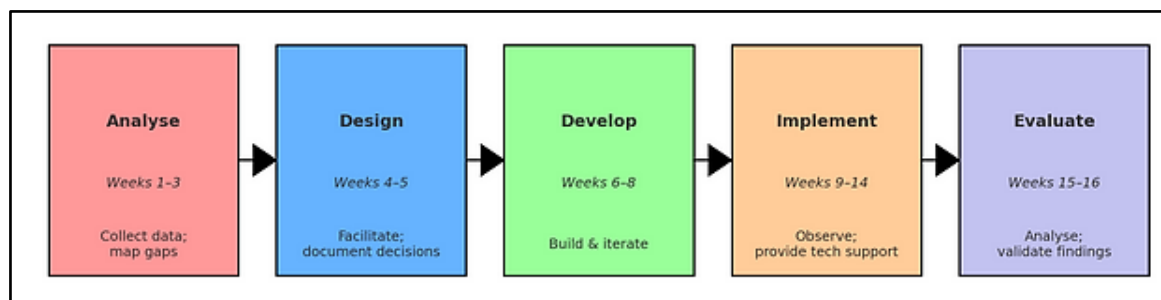


Figure 2: Flowchart of the Intervention Phase

A timeline diagram that visually represents the sequence of intervention sessions across the five phases. It shows how **Analyse → Design → Develop → Implement → Evaluate** unfolded over the 16 weeks of the study. It shows each phase in sequence, the corresponding weeks, and the researcher’s role, connected with directional arrows to illustrate progression.

3.4 Instruments and Measures

To evaluate outcomes aligned with the course’s learning goals, we combined validated self-report scales, structured observations, platform analytics, and qualitative inquiry. Where adaptations were necessary, we used best-practice translation procedures and inter-rater checks to preserve measurement quality, as in Table 2.

Table 2: Instruments and Measures

Construct	Instrument	Reliability	Sample Item
Digital literacy (5 UNESCO domains)	30-item Likert Digital Literacy Scale (adapted & back-translated)	Cronbach $\alpha = 0.87$	"I can verify the credibility of online chemistry sources."
Character education (respect, collaboration, stewardship)	Character Values Observation Rubric (5-point, 12 indicators) rated by two observers	Inter-rater $\kappa = 0.81$	Shares equipment responsibly during lab."
Engagement	Moodle analytics (time-on-task, clickstream)	System-logged	—
Qualitative insights	Semi-structured focus-group protocol (students $n = 24$; lecturers $n = 4$)	Member-checked summaries	"Describe a moment the course connected with your community knowledge."

3.5 Data Collection and Analysis Procedures

Quantitative tests and learning analytics provide measurable evidence of the magnitude and significance of educational interventions. For instance, learning analytics can track student engagement and performance, offering data-driven insights into learning processes (Hilliger *et al.*, 2020). In the context of online learning, quantitative surveys have been used to assess student satisfaction and identify challenges, such as a lack of community and concerns about well-being (Brown *et al.*, 2023). Learning analytics frameworks, such as those discussed in the literature, emphasize the importance of data quality and technological readiness for effective implementation (Clark, Liu and Isaias, 2020).

Focus groups and thematic analysis are instrumental in uncovering the underlying mechanisms and contextual factors influencing educational outcomes. These methods enable exploration of student and staff perceptions, providing a deeper understanding of their experiences (Brown *et al.*, 2023). Thematic analysis has been used to identify key themes in students' experiences, such as facilitators and barriers to learning, which inform practice recommendations (Brown *et al.*, 2023).

Qualitative data from interviews and focus groups can reveal diverse stakeholder needs and priorities, as seen in studies on learning analytics adoption (Hilliger *et al.*, 2020). The evaluation of the design artefact is crucial for assessing the quality of implementation. This involves examining the educational design principles and their impact on learning outcomes (Müller, Mildenerger and Steingruber, 2023a). Studies have highlighted the importance of an adequate course structure, activating learning tasks, and timely feedback in enhancing the

effectiveness of blended learning programs (Müller, Mildenerger and Steingruber, 2023b). The evaluation process can also provide critical feedback for refining educational approaches, such as flipped learning, by considering stakeholder perspectives and experiences (Simmons *et al.*, 2020).

Pre- and post-test scores were computed for each participant, screened for normality using the Shapiro–Wilk test, and analyzed with paired-samples *t*-tests at $\alpha = .05$ to determine the significance of gains; effect sizes were reported as Cohen’s *d*. Learning management system (LMS) traces were exported as CSV files, cleaned (e.g., removal of idle-time outliers), and correlated with individual learning gains using Pearson’s *r*. Focus-group recordings were transcribed verbatim and imported into NVivo 14 for thematic analysis using a hybrid approach that combined deductive codes (drawn from the Digital Literacy Global Framework and the target virtue categories) with inductive, data-driven codes; credibility was strengthened through analyst triangulation and participant member-checking of summary interpretations. Model fidelity was appraised with a 15-item usability/fidelity checklist, yielding a mean score of $M = 4.4/5$, indicating high alignment between the intended design and its enacted implementation.

4. Findings and Discussion

4.1 Learning-Management-System Analytics

We analyzed Moodle trace data over Weeks 9–14 to quantify behavioral engagement and relate it to a key design feature (the AR dye-extraction lab). Metrics include interaction volume, time-on-task trends, and feature uptake, with inferential testing via repeated-measures ANOVA to assess change over time as in Table 3.

Table 3: Summary of LMS Engagement Metrics (Weeks 9–14)

Metric	Value	How to read it
Total interactions (page views + quiz attempts)	14,678	Aggregate activity across all students and weeks
Analytic sample size	N = 120	From ANOVA df: F(1, 119)
Interactions per student (6 weeks)	≈122	14,678 / 120 ≈ 122 → ≈20/week
Mean time-on-task (Week 9 → Week 14)	31 → 52 min/week	+21 min total change (+67.7%)
Average weekly increase in time-on-task	+4.2 min/week	Linear rise across Weeks 9–14
Linear trend (RM-ANOVA)	F(1,119) = 38.7, p < .001	partial $\eta^2 = .25$ (large effect)
AR lab uptake (Week 12)	92% accessed	≈110 of 120 students
AR activity dwell time (median)	11 min	+46% vs course-wide median (~7.5 min)

Engagement increased significantly during implementation ($F(1,119) = 38.7, p < .001$; partial $\eta^2 = .25$). Time-on-task rose from 31 to 52 minutes per week (+67.7%), with about 20 interactions per student weekly. The Week 12 AR lab boosted engagement (92% participation; 11-minute median). Interactive activities mid-semester can sustain momentum. Engagement data should be carefully measured and linked to learning outcomes.

4.2 Digital-literacy Gain Scores

Pre- and post-administration of the 30-item Digital Literacy Scale (DLS) met normality assumptions (Shapiro–Wilk $ps > .10$), permitting paired-samples *t* tests. Results show substantial improvements across all UNESCO domains and overall DLS, with consistently significant effects as in Table 4.

Table 4: Digital Literacy Pre–Post Comparisons

DLS Domain	MPre (SD)	MPost (SD)	Gain (Δ)	% Change	t(119)	p	Cohen’s <i>d</i>
Information/Data	11.9 (3.0)	17.4 (2.6)	5.5	46.2%	15.80	< .001	1.44
Communication	10.8 (2.7)	15.0 (2.5)	4.2	38.9%	14.23	< .001	1.30
Content Creation	12.4 (3.1)	17.6 (2.8)	5.2	41.9%	16.12	< .001	1.47
Safety	10.5 (2.9)	13.8 (2.4)	3.3	31.4%	11.77	< .001	1.07
Problem-Solving	10.7 (2.8)	14.0 (2.3)	3.3	30.8%	12.89	< .001	1.18
Overall	56.3 (9.7)	77.8 (8.1)	21.5	38.2%	14.62	< .001	1.34

The findings show great improvement in students’ digital literacy across all UNESCO domains within one semester. The largest gains were in Content Creation ($d = 1.47$) and Information/Data ($d = 1.44$). Communication ($d = 1.30$), Safety ($d = 1.07$), and Problem-Solving ($d = 1.18$) also improved significantly. All effect sizes were large ($d > 1.0$), indicating a meaningful impact. Integrating culturally responsive pedagogy with accessible technology effectively strengthened digital competence. Figure 3 to visually represent the pre- and post-test gains in digital literacy, and an effect size (Cohen’s d) visualization to emphasize the magnitude of improvements across domains.

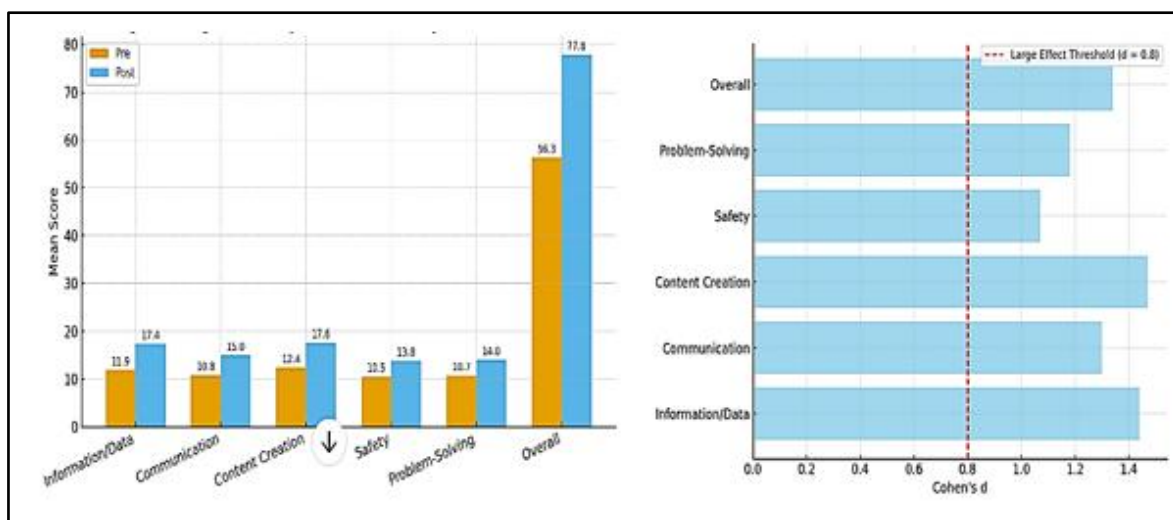


Figure 3: Digital Literacy Pre–Post Means by Domain

The chart shows consistent pre→post gains across all UNESCO domains and the overall DLS score. Visually, the “Post” bars exceed “Pre” bars for every domain, mirroring the significant paired t -tests and large effects reported earlier (all $d \geq 1.07$). The steepest lifts appear in Content Creation and Information/Data, aligning with coursework that emphasized producing artifacts and evaluating sources. Safety improved the least (though still strongly), suggesting an opportunity to bolster privacy, security, and digital well-being activities in future iterations. The overall increase substantiates broad competence growth within a single semester, reinforcing that the instructional model was not domain-specific but systematically elevated digital literacy. The dashed red line marks the conventional threshold for a “large” effect size ($d = 0.8$), illustrating that all observed improvements exceeded this benchmark substantially.

4.3 Character-Education Outcomes

Character education was assessed using a 12-indicator rubric that captured students’ observable behaviors across five in-class collaborative tasks. Two trained observers made ratings on a 0–4 scale, with strong interrater reliability ($\kappa = 0.81$). For analysis, mastery was defined as scores of 3 or higher. Results indicate significant post-intervention improvements across all domains, reflecting the integration of Merdeka Belajar values and local cultural knowledge into the HyFlex model, as in Table 5.

Table 5: Mastery Rates on Character Domains (≥ 3 on 0–4 rubric)

Character Domain	Baseline %	Post %	Δ (pp)	Relative Increase	Risk Ratio	Cohen’s h
Respect for Local Wisdom	42%	68%	+26	+61.9%	1.62	0.53
Collaboration	47%	71%	+24	+51.1%	1.51	0.49
Environmental Stewardship	35%	54%	+19	+54.3%	1.54	0.39

Notes. McNemar tests confirmed significant paired gains in all domains (χ^2 range **22.3–29.7**, $ps < .001$). Cohen’s h provides a standardized magnitude for proportion shifts; values $\sim 0.2/0.5/0.8 \approx$ small/medium/large. Effects were medium to large. In a cohort of about 120 students, gains equal roughly 31 more students reaching mastery in Respect, 29 in collaboration, and 23 in stewardship. All domains improved significantly (McNemar $\chi^2 < .001$). The largest gain was respect (+26 pp), followed by collaboration (+24 pp) and stewardship (+19 pp). Reliability was strong ($\kappa = 0.81$). Adding targeted environmental roles may further strengthen stewardship outcomes.

4.4 Qualitative Insights

To complement quantitative measures, qualitative insights were gathered through semi-structured focus groups with 24 students and four lecturers. Transcripts were coded inductively, and thematic analysis identified three high-salience themes that reveal how the intervention influenced participants’ perceptions, cultural connections, and digital learning behaviors. These themes provide contextual depth to the observed gains in digital literacy and character education.

The first theme, **“Seeing Chemistry in Our Culture,”** illustrates how the AR dye-lab experience bridged disciplinary knowledge with local traditions. Students’ realization that “chemistry already lives in my village” reflects the success of situating scientific learning within cultural heritage, fostering both relevance and pride.

The second theme, **“Learning by Teaching Elders,”** demonstrates the reciprocal nature of the service-learning activities. By creating infographic posters for community dye practices, students not only disseminated knowledge but also developed humility and respect through intergenerational dialogue. This aligns directly with gains observed in respect for local wisdom and collaboration.

The third theme, **“Digital Confidence,”** highlights students’ growing ability to evaluate online information critically. Statements such as “Now I check who wrote the article before I copy anything” indicate that the intervention cultivated transferable critical-search skills, supporting the quantitative evidence of substantial improvements in the Information/Data and Communication domains of digital literacy.

These themes portray a virtuous cycle: culturally situated activities sparked relevance, service-learning cemented social purpose and collaborative norms, and explicit search/credibility scaffolds matured into agency. The convergence with quantitative results (engagement lift, significant DLS effects, gains in character domains) strengthens confidence that the observed improvements reflect genuine learning rather than test familiarity.

4.5 Model Fidelity and Usability

To assess the quality and consistency of implementation, external observers applied a 15-item fidelity checklist, and lecturers completed usability surveys regarding integration and student engagement. These measures were selected to evaluate not only whether the intervention was delivered as designed but also how it was experienced by instructors responsible for sustaining the model. Results indicate strong fidelity and positive perceptions of usability, with some noted challenges in workload management during the production phase, as in Table 6.

Table 6: Fidelity and Usability Summary

Measure	Scale	Result	Interpretation	Notes
External fidelity checklist (15 items)	1–5 per item	M = 4.4, SD = 0.3	High adherence to design intentions	Observers noted precise flipped sequencing, explicit virtue prompts, and materials optimized for low bandwidth.
Usability: ease of integration into syllabus	1–7 Likert	M = 6.1	Very usable for course embedding	Lecturers reported smooth mapping to existing weeks and assessments.
Usability: perceived student engagement	1–7 Likert	M = 6.4	High perceived engagement	Perceptions align with LMS analytics peaking around the AR lab.
Implementation burden (qualitative)	—	Workload spikes	Targeted constraint rather than systemic barrier	Spikes concentrated during video production and curation for flipped sessions.

Fidelity scores near the ceiling (4.4/5) indicate the model was enacted as intended in a resource-constrained Papuan context, preserving its core pillars (flipped flow, virtue alignment, low-bandwidth access). High lecturer ratings for ease of integration (6.1/7) and perceived engagement (6.4/7) suggest strong practical viability and face validity, echoing quantitative engagement lifts and qualitative reports of relevance.

The primary caveat is production workload—notably for video creation—implying that the model’s most substantial returns occur when media assets are front-loaded or shared. Pragmatic next steps include (a) a reusable asset library (short, modular clips), (b) co-creation with students to distribute effort, and (c) low-bandwidth-first templates (scripts, slide skeletons) to minimize editing time.

Bottom line: Taken with the mixed-method results reported elsewhere (large digital-literacy gains, significant increases in character-value mastery, and upward LMS trends), these fidelity and usability findings show the model is both practical and implementable—with a clear, solvable pinch point in media production.

5. Discussion

5.1 Answering the Research Questions

The Transformative Ethnochemistry Lecture Model significantly addresses gaps in students' digital literacy and character development within educational environments with limited technological resources. The model uses a flipped HyFlex teaching approach, which research indicates can enhance student engagement and motivation in learning, particularly in contexts focused on digital literacy. A study highlights that implementing flipped classroom strategies can substantially improve students' awareness and responsibility in their learning journey (Torres, Mouro and Mesquita, 2024). Furthermore, incorporating local ethnochemical cases alongside relevant digital tasks is essential for fostering digital literacy, especially in environments constrained by bandwidth limitations, as the literature on ethnochemistry education's effectiveness suggests (Ridwan, Hadi and Jailani, 2022).

Quantitative assessments show that students' digital literacy skills saw considerable enhancement, with effect sizes reported around $d \approx 1.3$ to 1.5 across various domains, corroborating findings in studies focused on the impact of integrated digital tasks in educational models (Tour *et al.*, 2023). This improvement can be attributed to the interactive and participatory nature of the flipped HyFlex model, which aligns with findings from digital literacy frameworks emphasizing engagement through contemporary pedagogical strategies (Saputri, Muchtarom and Triyanto, 2019). In addition to digital skills, character outcomes, including respect for local wisdom, collaboration, and environmental stewardship, exhibited measurable improvements, increasing by approximately 19-26 percentage points among students (Murphy and Arciuli, 2024). Integrating community-driven initiatives, such as field-trip service-learning, allows students to engage meaningfully with their environments, resulting in authentic experiences that translate moral reasoning into actionable steps (Rahmawati and Agustini, 2023). Reflective practices through journaling reinforce this growth by encouraging students to connect their experiences with character education principles, thereby significantly transforming educational outcomes when embedded directly into task rubrics (Suroso and Husin, 2024).

Key factors contributing to these enhancements include authentic engagement with local communities through an educational lens, documented as vital for character development and for establishing students as active participants in sustainability efforts (Rahmawati and Atmojo, 2023). By embedding local wisdom and context-specific knowledge into the learning process, students gain a deeper understanding of their cultural identities and their relationship with environmental sustainability, which is essential for character education in contemporary contexts (L. Heliawati *et al.*, 2022). Thus, the Transformative Ethnochemistry Lecture Model not only bridges digital literacy gaps for students in resource-limited environments but also cultivates a profound respect for local wisdom and environmental responsibilities, indicative of a robust character education framework.

5.2 Positioning Within Prior Literature

The findings from the Transformative Ethnochemistry Lecture Model reveal advances in both digital literacy and character education. The observed improvements in digital literacy suggest that integrating culturally relevant content enhances the motivational aspects of technology-enhanced learning. Effect sizes reported in recent flipped-STEM meta-analyses indicate improvements in student engagement and digital competency when culturally situated content is applied (Colque-Quispe *et al.*, 2025).

Furthermore, the model's impact on character education supports Lickona's assertion that virtues thrive when embedded in community-linked, project-based learning environments. Evidence shows that character outcomes improve significantly when moral education is connected to practical contexts rather than relying solely on traditional, abstract storytelling. Engaging students in community involvement and hands-on experiences can enhance moral development and deepen their engagement with the subject matter, corroborated by research on effective community-oriented educational strategies (Suroso & Husin, 2024; Sitanggang *et al.*, 2025).

The current study builds upon previous educational initiatives in Indonesia, emphasizing the significance of cultural relevance in enhancing student engagement and performance in ethnochemistry. Notably, it is the first to empirically connect cultural relevance with scaffolding in digital skills and systematic virtue assessment (Rahmawati *et al.*, 2023). This approach aligns with advocacy for integrating digital literacy into culturally

responsive teaching practices and supports sustainable educational paradigms that foster both digital competencies and ethical character development (Torres, 2024). This study highlights the importance of a holistic educational approach that blends technological engagement with culturally relevant pedagogies, ultimately promoting both digital literacy and character development in students.

5.3 Implications for Practice and Policy

Utilizing the Transformative Ethnochemistry Lecture Model has implications beyond initial educational results. It influences curricular design, faculty development, and policy leverage in STEM education, particularly in peripheral regions.

Chemistry departments in similar peripheral regions can effectively adopt the design principles derived from Design-Based Research (DBR) that emphasize cultural anchoring, low-bandwidth technology, and virtue-aligned assessment. This approach is expected to revitalize other STEM disciplines, such as ethnobotany and mineral processing, by creating content that resonates with local cultural contexts. Ethnochemistry enhances engagement and understanding in chemistry by linking abstract concepts to students' cultural practices (Rahmawati et al., 2023). Incorporating culturally relevant materials not only makes learning more relatable but also enhances comprehension and retention of complex scientific ideas (Yanti et al., 2025b).

Given the necessity for innovation in instructional design, faculty members require structured support in multimedia authoring and integrating virtual-infused task design strategies. Establishing a micro-credential program focused on digital competencies could institutionalize essential skills for educators. Such initiatives promote a proactive stance in addressing educational gaps in technology and in character education conformity, which are essential for preparing students for the demands of contemporary educational environments (Rathod and Kämpfi, 2025).

The findings of this study provide empirical evidence supporting character education objectives that can coexist synergistically with rigorous, digitally enhanced science instruction. This dual focus could serve as a compelling argument to policymakers for securing funding for rural broadband upgrades, which are critical to expanding access to digital resources and innovative teaching methods in underserved areas. Additionally, demonstrating the feasibility of integrating virtue and character education into STEM fields is pivotal in advocating for more inclusive educational policies (Hafina, Nur and Malik, 2022). The evidence presented underscores the importance of community integration in educational practices, which can enhance student engagement and achievement (Phelan, Maguire and Finnegan, 2025).

By embracing culturally responsive pedagogies and digital literacy frameworks, policymakers and educational institutions can bolster the educational ecosystem in peripheral regions, ensuring that students are not only technologically adept but also well-rounded individuals grounded in their cultural values.

6. Conclusion

This study set out to re-envision an Ethnochemistry Technology course for Papua Indonesia by weaving together three strands that are seldom integrated in STEM higher education: indigenous chemical heritage, explicit digital-literacy scaffolding, and character-education mandates from the *Kurikulum Merdeka*. Through a semester-long Design-Based Research cycle, the resulting Transformative Lecture Model achieved three salient outcomes. First, it delivered large, statistically significant gains in all five UNESCO Digital Literacy domains—demonstrating that low-bandwidth, flipped HyFlex design can close digital-skills gaps even in infrastructure-limited regions. Second, rubric-based observations showed marked growth in respect for local wisdom, collaboration, and environmental stewardship, validating the potency of virtue-aligned tasks such as service-learning with village elders. Third, strong LMS engagement metrics and high fidelity scores indicate that the model is both pedagogically robust and practically implementable.

Strengths include the mixed-methods DBR approach, strong fidelity monitoring, and genuine community partnership—all of which bolster ecological validity. *Limitations* revolve around scope (single university), duration (one semester), and potential observer bias in character-rubric scoring despite high κ . Replication across multiple Papuan and non-Papuan campuses, using blinded assessors and longitudinal follow-ups, would test generalisability and persistence of effects. Scalability studies should also explore automated content-translation pipelines to accommodate additional indigenous languages.

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