Designing a STEAM-Based Ethnophysics Model to Strengthen Digital Literacy and Self-Regulated Learning

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ABSTRACT

Digital transformation requires students who can critically evaluate information, collaborate online, and create digital products responsibly, yet technology-rich instruction often lacks explicit digital literacy (including foundational computer literacy) and self-regulated learning (SRL) scaffolds. This paper proposes the ESED (Ethnophysics-based STEAM model for digital literacy and SRL) instructional model, which integrates local Ethnophysics phenomena with STEAM design challenges to develop assessable digital competence and SRL in secondary science. Using an educational design research (design-and-development) logic, recent evidence on STEAM, SRL, and the DigComp 2.2 framework was synthesized and translated into six iterative phases: Cultural Anchoring; Inquiry & Data Literacy; STEAM Design Challenge; Digital Production; Reflection & Regulation; and Dissemination & Civic Action. Each phase specifies teacher roles, learner activities, digital tools, and assessment indicators aligned with DigComp competence areas and SRL cycles. Practical supports include a topic–phenomenon mapping, an assessment matrix, and an illustrative unit plan. As a design-product report, this paper does not present classroom trial data; instead, it offers a transparent blueprint intended for expert review and future empirical validation.

Keywords
STEAM education; Ethnophysics; Digital literacy; Self-regulated learning; Physics education

Introduction

Digital transformation has intensified the demand for students who can learn autonomously, evaluate information critically, collaborate online, and create digital products responsibly. These capabilities, often framed as digital literacy or digital competence, are increasingly linked to participation in education, work, and civic life (Vuorikari et al., 2022; Wang et al., 2024). At the same time, evidence from school digitalization shows that technology does not automatically improve learning: impacts depend on school digital capacity, teacher support, and pedagogical design (Haleem et al., 2022; Timotheou et al., 2023). In many contexts, particularly after increased use of blended and mobile learning, students face new demands such as navigating fragmented information, managing attention, and coordinating collaboration across platforms, demands that make self-regulated learning (SRL) crucial. In physics and science learning, these demands are intensified because learners must coordinate data, multiple representations, and modelling while working with digital tools.

However, in many schools, digitalization is still implemented as tool adoption rather than competence-oriented learning design. Students' computer literacy, namely basic operational skills such as managing files, using spreadsheets for data work, configuring accounts safely, and troubleshooting common issues, varies widely. When these foundational skills are not scaffolded, technology-rich projects can devolve into superficial browsing, copy–paste products, or poorly documented data work. Therefore, digital literacy needs to be intentionally operationalized into observable indicators and assessed within subject learning rather than assumed as a by-product of using devices (Vuorikari et al., 2022; Timotheou et al., 2023).

SRL refers to learners' capacity to plan, monitor, and reflect on learning while regulating cognition, motivation, and behaviour. Recent syntheses show that SRL is a reliable predictor of achievement in online and blended environments and that specific strategies (e.g., time management, effort regulation, metacognitive strategy) matter for learning outcomes (Xu et al., 2023; Zhao et al., 2025). Yet, SRL is not evenly developed across learners, and many students need explicit scaffolds to regulate their digital learning activity.

Physics education provides a relevant context for addressing these challenges (information evaluation, data handling, online collaboration, and self-regulation in digital learning). Physics concepts are often abstract and require learners to coordinate multiple representations (models, graphs, simulations) while engaging in disciplined inquiry. However, when physics instruction is disconnected from students lived experiences, it can feel remote and reduce persistence and strategic engagement. Ethnophysics draws on local culture, indigenous technologies, and community practices as contexts for learning physics and offers a pathway to make physics meaningful and culturally sustaining (Festiyed et al., 2024; Saputra et al., 2024). Recent work illustrates that Ethnophysics resources and mobile learning can support conceptual understanding and learning independence when culture is treated as a knowledge resource rather than a decorative example (Batlolona et al., 2022; Lestari & Apsari, 2022).

Meanwhile, STEAM education (Science, Technology, Engineering, Arts, and Mathematics) is promoted to integrate disciplinary knowledge with creativity, problem solving, and production of tangible artifacts. Systematic reviews indicate that STEAM interventions can support achievement and skill development, particularly when organized around design challenges and authentic contexts (Amanova et al., 2025; Yim et al., 2024). Arts integration can enrich meaning-making through visualization, storytelling, and human-centred design (Sanz-Camarero et al., 2023; Silva-Hormazábal & Alsina, 2023). However, a persistent gap remains: many STEAM implementations treat technology use broadly, without explicitly operationalizing digital literacy competences or embedding SRL scaffolds that help learners regulate their digital work overtime (Deák & Kumar, 2024; Timotheou et al., 2023). Similarly, Ethnophysics studies often focus on contextualizing concepts but provide limited guidance on integrating interdisciplinary STEAM workflows and assessable digital literacy outcomes into one coherent design.

Despite these benefits, STEAM projects can also face practical limitations in schools: curriculum time pressure, uneven teacher expertise across disciplines, assessment complexity, and the risk that students prioritize product aesthetics or tool use over conceptual explanation. These constraints strengthen the need for explicit learning outcomes, checkpoints, and rubrics that keep physics reasoning central.

This article addresses this gap by proposing and specifying a STEAM-based Ethnophysics instructional model deliberately engineered to strengthen digital literacy (including foundational computer literacy) and SRL. The model is intended for secondary science/physics but can be adapted to other levels and subjects. The guiding research questions are: (1) What design principles and learning phases are required to integrate Ethnophysics with STEAM while explicitly targeting digital literacy and SRL? (2) How can the model be operationalized through mapping tools, assessment indicators, and an illustrative unit plan that support replication and local adaptation? Because the present study focuses on model development, the contribution is a design specification and model-analytic mapping rather than empirical effectiveness claims.

Literature Review

STEAM as an Interdisciplinary Learning Architecture

Across recent reviews, STEAM is characterized by integrated inquiry and engineering design in which learners build disciplinary understanding through iterative creation of products, performances, or solutions (Amanova et al., 2025; Yim et al., 2024). The "A" in STEAM supports multiple functions: aesthetic design (e.g., layout, visual communication), artistic expression (e.g., storytelling and performance), and human-centred considerations (e.g., empathy, cultural meaning). Reviews focusing on arts integration suggest that STEAM can strengthen students' engagement and representational competence when teachers explicitly link artistic choices to scientific reasoning and assessment criteria (Sanz-Camarero et al., 2023). For teacher education, STEAM can also broaden pedagogical repertoires and encourage interdisciplinary collaboration, but only when learning goals are clear and teachers are supported with practical planning tools (Silva-Hormazábal & Alsina, 2023).

From a design perspective, STEAM can be understood as a workflow consisting of problem framing, inquiry and evidence generation, design ideation, prototyping, testing, and communication. This workflow aligns naturally with competence-based approaches because it yields observable artifacts and decision trails (e.g., data tables, prototypes, portfolios) that can be assessed. However, STEAM projects can become superficial when students emphasize tool use or product appearance without sufficient grounding in disciplinary concepts. Thus, recent STEAM reviews highlight the need for scaffolds that support conceptual explanation, evidence use, critique, and iteration (Deák & Kumar, 2024; Leavy et al., 2023).

Ethnophysics and Culturally Grounded Science Learning

Ethnophysics investigates how cultural artifacts, practices, and local technologies embody physical principles. A systematic review of Ethnophysics studies in Indonesia documents growing efforts to connect cultural phenomena (traditional games, dances, musical instruments, architecture, and community technologies) with physics topics such as motion, forces, waves, heat, and electricity, while recommending deeper instructional translation and wider coverage across regions (Festiyed et al., 2024). Ethnophysics designs can also be linked to cultural heritage education; sustainability-oriented scholarship argues that cultural heritage can serve as a bridge between identity, community values, and future-oriented competencies in digitalized education (Orphanidou et al., 2024).

Empirical Ethnophysics work indicates that culturally contextualized learning materials can support conceptual understanding and motivation when students actively engage in inquiry rather than passively receiving cultural examples. For instance, a case study linking the Tifa musical instrument to physics concepts explored conceptual understanding through culturally relevant phenomena (Batlolona et al., 2022). In addition, Ethnophysics-based mobile learning in the Hombo Batu context was reported to increase learning independence and outcomes through accessible, context-rich digital activities (Saputra et al., 2024). An important design implication is that Ethnophysics needs a disciplined translation process: (a) represent culture authentically and ethically, (b) identify physics principles embedded in the phenomenon, (c) design measurement and modelling tasks that allow evidence-based explanation, and (d) connect the phenomenon to meaningful application through engineering and creative expression.

Digital Literacy and Digital Competence

Digital literacy is increasingly framed as a set of competences rather than merely tool familiarity. DigComp 2.2 specifies five competence areas: information and data literacy; communication and collaboration; digital content creation; safety; and problem solving, with detailed descriptors and examples of knowledge, skills, and attitudes (Vuorikari et al., 2022). Digital competence is also linked to broader educational change agendas; bibliometric analyses show rising global attention to digital technologies as drivers of education reform (Wang et al., 2024). Despite this attention, technology adoption can reproduce inequalities if schools and learners have unequal access to devices, connectivity, and digital support (Timotheou et al., 2023).

In physics classrooms, digital competence can be operationalized through concrete practices such as organizing and cleaning measurement data in spreadsheets, exploring parameters in simulations, co-authoring explanations in shared documents, and producing annotated graphs, portfolios, or short videos that connect evidence to physics claims. For classroom implementation, the challenge is to make digital competence observable and assessable within subject learning. Recent work in educational measurement provides validated indicators for adolescent digital literacy, emphasizing information evaluation, responsible use, and productive creation (Avinç & Doğan, 2024). In STEAM contexts, digital competences are strengthened when students use digital tools as “knowledge workspaces”: gathering data, organizing evidence, co-authoring explanations, and publishing artifacts for an audience (Deák & Kumar, 2024). Thus, digital literacy should be treated as an outcome of disciplined participation in inquiry and design, not an add-on skill taught separately.

Self-regulated Learning in Digital and Blended Learning Environments

SRL is consistently associated with achievement in online and blended learning. A recent scoping review synthesizing SRL research in digital and blended contexts highlights that successful learners employ cycles of planning, monitoring, control, and reflection and that instructional support for these processes is particularly needed in environments with high learner autonomy (Xu et al., 2023). Complementing this, a meta-analysis focusing on online/blended contexts found a small but significant overall correlation between SRL strategies and achievement and identified time management, effort regulation, metacognitive strategy, and organization as operational strategies most consistently associated with performance (Zhao et al., 2025).

SRL can also be supported through personalization and adaptive learning designs. For example, research on personalized learning approaches for self-regulated online learning provides design implications such as goal-setting prompts, progress dashboards, and feedback loops that help learners monitor and adapt strategies (Ingkavara et al., 2022). These insights suggest that culturally grounded STEAM projects should embed SRL supports as routine learning artifacts (e.g., design logs, checklists, reflection prompts) rather than relying on students' spontaneous regulation.

Synthesis and Research Gap

Although STEAM, Ethnophysics, digital literacy, and SRL each have growing evidence bases, existing implementations often treat these elements in parallel rather than as a coordinated system with explicit learning outcomes and assessment. What is needed is a model that specifies (a) how Ethnophysics phenomena are transformed into inquiry and design tasks, (b) how each learning phase targets and evidences digital competence, and (c) how SRL is scaffolded through routines and artifacts. The next sections present such a model and the operational tools to implement it.

Methods

Research Design

This article reports a design product (an instructional model) developed using an educational design research (EDR) logic, also commonly termed design and development research (DDR). In this approach, the main outcome is a replicable design specification (principles, phases, and tools) that can be subjected to expert review and later validated through classroom trials. The present paper represents the model-development/prototype-specification stage; it does not report a Delphi consensus study or an empirical effectiveness experiment. Accordingly, analysis in this paper is model-analytic (framework alignment and competence coverage mapping) rather than statistical analysis of participant data.

The ESED model was developed through an iterative cycle of (a) problem analysis and evidence synthesis, (b) framework alignment to DigComp 2.2 and SRL cycles, (c) drafting and refining the model phases and supporting artifacts, and (d) internal consistency checks through model-analytic mapping (reported in the Results section).

Four design requirements guided the model construction: (R1) Cultural authenticity and ethical representation: cultural practices are described respectfully, with community consultation and attention to intellectual/cultural ownership; (R2) Conceptual rigor: Ethnophysics contexts are linked to measurable physics variables, models, and explanations, avoiding superficial 'culture as decoration'; (R3) Explicit digital competence outcomes: learning tasks are mapped to DigComp 2.2 competence areas and produce evidence of competence (Vuorikari et al., 2022); (R4) Embedded SRL scaffolding: learning routines explicitly support planning, monitoring, strategy use, and reflection, based on recent syntheses of SRL in digital learning (Xu et al., 2023; Zhao et al., 2025).

Participants/Samples

Because this paper reports the initial design/prototype specification, no student sample or teacher participants were recruited, and no classroom trial was conducted. The unit of analysis is the ESED model specification and its supporting design artifacts. Participant-based validation is proposed for subsequent stages, such as (i) expert review for content validity (cultural authenticity, physics accuracy, and indicator relevance), (ii) a small-scale pilot for feasibility, and (iii) field trials for effectiveness.

Design Artifacts and Operational Tools

The model is accompanied by four operational design artifacts intended to support replication, classroom enactment, and future validation:

1. Phase map (see Table 1) describing learning phases, teacher roles, student actions, and suggested digital tools.
2. Ethnophysics–STEAM topic mapping (see Table 2) illustrating how cultural phenomena can be linked to physics concepts and design outputs.
3. Assessment matrix (see Table 3) aligning DigComp competence indicators and SRL indicators with observable evidence and scoring suggestions.
4. Illustrative unit plan (see Table 4) showing how phases can be scheduled across weeks and how evidence is collected.

Table 3 functions as an analytic rubric for digital competence (including foundational computer literacy such as basic data handling, file/version management, and tool troubleshooting) and SRL processes enacted during projects. Because ESED relies on portfolios and rubrics, quality criteria should be reported transparently in empirical studies. First, content validity can be supported by expert judgment on whether each indicator appropriately represents the intended competence (e.g., DigComp descriptors and SRL indicators) and whether cultural representation is accurate and respectful. Second, scoring reliability can be strengthened through rater training and interrater agreement checks when multiple assessors evaluate artifacts. Third, triangulation is recommended: combine rubric scores with process evidence (version history, learning logs, peer feedback) to reduce the risk of grading only the final product. Finally, transparency for learners is essential: provide rubrics early, use exemplars of high-quality work, and require short rationales that connect design choices to physics evidence. These reporting practices help ensure that competence claims are credible and that assessment supports learning rather than merely auditing outcomes.

Design Procedure and Model-Analytic Mapping

Model development and analysis involved four iterative steps:

1. Evidence-informed synthesis: A focused review of recent peer-reviewed studies (primarily 2021–2025) on STEAM, digital literacy/digital competence, SRL, and Ethnophysics was used to extract recurring design mechanisms and practical implications for instruction and assessment.
2. Framework alignment: Extracted implications were mapped to DigComp 2.2 competence areas (Vuorikari et al., 2022) and to SRL cycles and strategies identified in recent syntheses (Xu et al., 2023; Zhao et al., 2025).
3. Model specification: Ethnophysics contexts were translated into STEAM design challenges using a “phenomenon-to-principle-to-product” procedure: local phenomena → physics concepts and measurements → interdisciplinary design tasks → digital artifact production and sharing.
4. Model-analytic mapping (internal validation): Each ESED phase was mapped to DigComp 2.2 competence areas and to SRL cycle components (planning, monitoring/control, reflection/adaptation) based on the teacher scaffolds, student actions, and assessment evidence specified in Tables 1–3. We summarize this mapping as a descriptive coverage tally (the count of DigComp competence areas and SRL components explicitly addressed in each phase). The tally is used to make the model’s competence claims transparent and to check that competence demands are distributed across phases, not to infer learner performance.

For empirical validation, future studies may triangulate expert review, classroom observation, and student performance evidence. Recommended steps include: (i) expert validation of cultural authenticity, physics accuracy, and indicator relevance (e.g., content validity studies or Delphi-style panels); (ii) a small-scale pilot for feasibility and usability; and (iii) classroom trials for effectiveness using pre–post measures of digital literacy (e.g., validated indicators for adolescents; Avinç & Doğan, 2024) and SRL, alongside conceptual understanding measures and portfolio-based evidence. Quantitative analysis may include descriptive statistics, reliability checks, and effect sizes. Qualitative analysis may include thematic coding of student reflections, design logs, and digital artifacts to examine how learners enact SRL and digital competences during each phase.

Results

Because this study is a design-product report, the results below consist of the ESED model specification and its operational artifacts (phase map, topic mapping, assessment matrix, and unit plan), followed by a model-analytic competence coverage mapping. No empirical classroom implementation data are reported in this paper.

The Proposed ESED Model

The ESED (Ethnophysics-based STEAM model for digital literacy and SRL) model organizes instruction into six iterative phases. The model treats culture as a starting point for inquiry, positions digital tools as spaces for knowledge work, and embeds SRL routines as part of every phase. The overall logic is cyclical: learners begin with a culturally meaningful phenomenon, investigate it with scientific inquiry and data practices, redesign it through engineering and artistic expression, publish digital artifacts, and reflect on both outcomes and processes. The phases are designed to produce evidence of digital competence (DigComp 2.2) and SRL at multiple points, rather than only at the end of the project. These six phases describe the instructional procedure (how teaching–learning is organized) derived from the design process described in the Methods section; they are not the research procedure.

Table 1
Phases of the ESED Learning Model

Phase	Core purpose	Teacher scaffolds	Student actions	Primary DigComp focus	Primary SRL focus
1. Cultural Anchoring	Elicit local phenomenon; build relevance; define driving question.	Curate authentic cultural media; invite community voice; co-define inquiry question; establish norms for respectful representation.	Observe/describe phenomenon; pose questions; set goals; plan roles and timeline; start a learning log.	Information & data literacy; communication (ethical sourcing).	Goal setting; planning; task value; time management.
2. Inquiry & Data Literacy	Investigate phenomenon with measurements, simulations, or data collection.	Provide inquiry protocol; model data quality checks; teach citation and data visualization routines; prompt monitoring.	Collect/clean data; use simulations/sensors; create graphs; evaluate sources; document decisions and uncertainties.	Information & data literacy; problem solving.	Monitoring; strategy selection; help-seeking.
3. STEAM Design Challenge	Translate findings into an interdisciplina	Facilitate brainstorming; guide constraints & criteria; connect	Generate design ideas; apply physics to constraints; sketch	Communication & collaboration; content creation (planning).	Strategic planning; effort regulation;

	ry design task and prototype concept.	physics principles to engineering and arts decisions.	storyboard; select tools; allocate responsibilities.		peer regulation.
4. Digital Production	Build and iterate a digital/physical artifact and accompanying explanation.	Provide tool tutorials; formative checkpoints; feedback cycles; safety and privacy guidance; manage versioning.	Produce prototype (model, simulation, infographic, video); iterate based on tests and feedback; keep version history.	Digital content creation; safety.	Self-monitoring; persistence; revision strategies.
5. Reflection & Regulation	Evaluate product quality and learning processes; make SRL explicit.	Use rubrics and reflection prompts; conferencing; support attribution and improvement plans; encourage evidence-based claims.	Self- and peer-assess; reflect on strategies and setbacks; revise goals; articulate next steps and transfer.	Problem solving; communication.	Self-evaluation; metacognitive reflection; adaptive decisions.
6. Dissemination & Civic Action	Share artifacts to authentic audience; connect to community impact.	Organize showcase; teach digital citizenship and licensing; support publishing and feedback etiquette.	Publish/present; respond to feedback; document learning; propose community-relevant improvements and future prototypes.	Communication & collaboration; safety; civic digital participation.	Transfer; sustaining regulation beyond classroom.

Ethnophysics-to-STEAM Mapping Examples

To support local adaptation, Table 2 illustrates how cultural phenomena can be transformed into physics ideas and STEAM outputs. Teachers should replace the examples with locally relevant practices after consultation with community members and students. The mapping emphasizes (a) identifying physics variables that can be measured, (b) designing an engineering task with constraints and criteria, and (c) selecting digital tools that enable data work and responsible publication.

Table 2

Example Mapping from Ethnophysics Phenomena to Physics Concepts and STEAM Products

Local phenomenon (example)	Physics focus	STEAM challenge (engineering + arts)	Digital tools/workspace	Possible outputs
Stone jumping / traditional athletic practice (e.g., Hombo Batu)	Impulse–momentum, projectile motion, energy transformation	Design a safe jump-training aid and a visual narrative explaining forces and motion	Video analysis app, simulation tools, collaborative whiteboard	Annotated video, force–time graph, prototype training aid, digital poster
Traditional musical instruments (e.g.,	Sound waves, resonance,	Engineer an adjustable resonator	Audio recorder + spectrum analyser,	Spectrogram report, resonator

drum/tifa, bamboo flute)	frequency, amplitude	and create a soundscape composition with scientific annotations	CAD/3D design, digital audio workstation	prototype, performance video
Cultural performance object with balance (e.g., masks, large costumes)	Centre of mass, torque, equilibrium	Redesign a balanced wearable structure; communicate aesthetics and stability trade-offs	3D modelling app, e-portfolio platform	3D model, balance test data, design portfolio
Local craft/architecture (e.g., woven patterns, stilt houses)	Statics, material strength, heat transfer (context dependent)	Build a scale model with material constraints and aesthetic criteria; test strength/thermal properties	Spreadsheet for measurements, design sketching, photo-documentation	Scale model, measurement table, mini-report, exhibition page
Community energy practice (e.g., fishing lights, battery use, micro-hydro)	Electric circuits, power, efficiency	Design an energy-saving circuit/device and explain efficiency improvements in community terms	Circuit simulator, data logger, infographic tool	Circuit prototype, efficiency dataset, infographic, explainer video

Assessment Matrix for Digital Literacy and SRL

Table 3 aligns DigComp competence areas and SRL indicators with observable evidence during STEAM-Ethnophysics projects. The matrix supports both formative assessment (ongoing feedback) and summative assessment (portfolio judgment) and can be implemented as an analytic rubric. In this paper, "computer literacy" is treated as a foundational subset of digital competence and is operationalized mainly within the digital content creation and problem-solving indicators (e.g., handling data in spreadsheets, managing files/version history, and troubleshooting tools responsibly). To increase transparency for students, teachers can convert indicators into student-friendly rubrics and checklists used at each checkpoint (e.g., after data collection, after prototyping, and after dissemination).

Table 3

Assessment Matrix Linking DigComp 2.2 Competences and SRL Indicators to Evidence in Student Work

Target competency/indicator	Operational definition (student can…)	Evidence sources	Scoring suggestion
Information & data literacy (DigComp) + Monitoring (SRL)	locate credible sources, document citations, collect and clean data, and monitor data quality	research log, citation list, dataset, graph revisions, data-quality checklist	0–3 rubric: missing → partial → adequate → rigorous/transparent
Communication & collaboration (DigComp) + Help-seeking/peer regulation (SRL)	coordinate roles, communicate respectfully online, request/offer help, and synthesize peer feedback	team agreements, role tracker, peer feedback forms, discussion evidence	0–3 rubric emphasizing constructive interaction and accountability

Digital content creation (DigComp) + Strategy use (SRL)	produce a digital artifact (video/infographic/simulation/portfolio) that accurately represents physics reasoning and design decisions	prototype files, version history, storyboard, design rationale, citation of media assets	0–4 rubric combining technical quality, creativity, and conceptual accuracy
Safety and digital citizenship (DigComp) + Effort regulation (SRL)	follow safety/ethics guidelines, protect privacy, and manage focus and screen time during production	media release checklist, reflection notes, teacher observation, digital footprint review	checklist + reflective justification
Problem solving (DigComp) + Reflection/adaptation (SRL)	identify problems, test alternatives, and revise plans after setbacks using evidence	debug notes, iteration cycles, reflection essay, improvement plan, test results	levels: emerging → developing → proficient → adaptive

Illustrative Unit Plan (example)

To illustrate implementation, Table 4 shows an example schedule for a 3-4-week unit (8–10 lessons) on an electricity/energy theme. The example is intentionally adaptable: teachers may adjust duration, tools, and the chosen local phenomenon. The unit emphasizes data literacy (measuring and comparing efficiency), collaborative design, and responsible publication of a digital artifact. In contexts with limited connectivity, dissemination can occur through offline showcases and local networks; digital artifacts can be compiled and shared later.

Table 4
Illustrative 3–4 Week Implementation Plan Aligned to ESED Phases

Week/lesson focus	ESED phase	Core activities	Digital workspace	Evidence collected
Week 1 (Lessons 1–2)	Cultural Anchoring	Introduce local phenomenon (e.g., community lighting, battery use, fishing lights); co-create driving question; set goals and roles; start learning log	Shared class folder/portfolio template; offline logs if needed	Goals, roles, initial questions, ethical agreement
Week 1 (Lessons 3–4)	Inquiry & Data Literacy	Investigate: measure voltage/current/power (or use simulations); compare energy use scenarios; evaluate sources; visualize data	Spreadsheet for data; simulation tool; citation manager (simple list)	Dataset, graphs, source notes, monitoring checklist
Week 2 (Lessons 5–6)	STEAM Design Challenge	Define design criteria (efficiency, safety, cost, cultural fit); brainstorm solutions;	Collaborative whiteboard; storyboard template	Design brief, criteria/constraints, plan and timeline

		sketch; plan prototype and media story		
Week 3 (Lessons 7–8)	Digital Production	Build prototype (circuit/device/model) and digital explanation (infographic/video); iterate based on tests; ensure safety and privacy	Version history folder; video editor/infographic tool	Prototype iterations, design log, media assets with citations
Week 3–4 (Lessons 9–10)	Reflection & Regulation + Dissemination	Peer review with rubric; revise; publish/present to class/community; reflect on SRL strategies and digital citizenship; propose improvements	Portfolio platform or compiled document; showcase	Final artifact, peer feedback, reflection essay, improvement plan

Model-analytic Results (Competence Coverage)

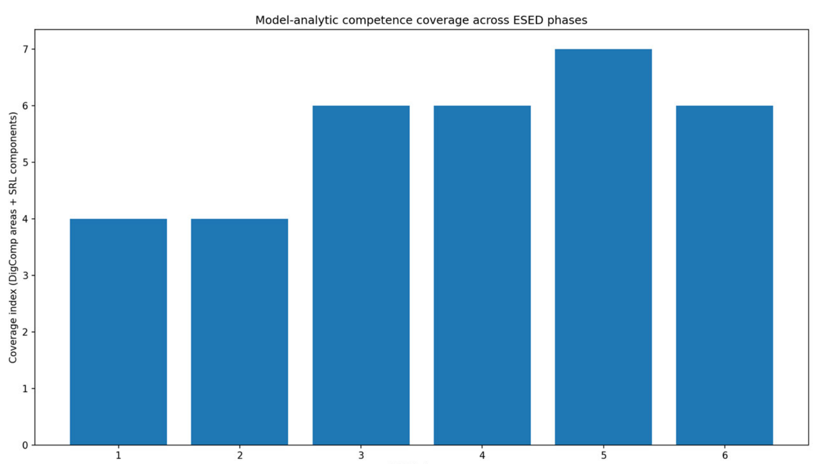
To make the model's competence claims transparent. To avoid confusion with empirical findings, we conducted a model-analytic mapping. Using the teacher scaffolds, student actions, and evidence sources specified in Tables 1–3, each phase was coded for which DigComp 2.2 competence areas are explicitly targeted and which SRL cycle components are emphasized (planning, monitoring/control, reflection/adaptation). Table 5 presents the mapping and a descriptive coverage tally (number of DigComp areas and SRL components explicitly addressed in each phase). As shown in Figure 1, this coverage index summarizes how each phase addresses DigComp areas and SRL components. The mapping indicates that the widest coverage occurs in Reflection & Regulation (Phase 5), where learners consolidate evidence, evaluate strategies, revise artifacts, and plan transfer. This analysis is descriptive: it checks internal coherence and balance of the model and does not constitute evidence of student competence.

Table 5
Model-analytic Mapping of DigComp Competence Areas and SRL Cycle Components across ESED Phases

Phase	Targeted DigComp areas	SRL cycle emphasis	Primary evidence points	Coverage index (CI)
1. Cultural Anchoring	Information & data literacy; Communication & collaboration; Safety/ethics (respectful representation)	Planning (goal setting, time management)	Driving question; goals/roles; ethical agreement; learning log; source notes	4
2. Inquiry & Data Literacy	Information & data literacy; Digital content creation (graphs/visualizations); Problem solving	Monitoring/control (monitoring data quality, strategy selection)	Dataset + graphs; data-quality checklist; research log + citations; uncertainty notes	4
3. STEAM Design Challenge	Information & data literacy (use evidence); Communication & collaboration; Digital	Planning + Monitoring/control (strategic planning, peer/effort regulation)	Design brief (criteria/constraints); storyboard; role tracker; design	6

	content creation (storyboard/plan); Problem solving		rationale linked to data	
4. Digital Production	Information & data literacy (testing); Communication & collaboration (feedback); Digital content creation; Safety (privacy/copyright); Problem solving (debugging/iteration)	Monitoring/control (self-monitoring, persistence, revision strategies)	Prototype + version history; safety/privacy checklist; debug notes; feedback records	6
5. Reflection & Regulation	Information & data literacy (evidence-based claims); Communication & collaboration (peer assessment); Digital content creation (revision); Safety (digital footprint); Problem solving	Reflection/adaptation + Planning (re-goaling for improvement/transfer)	Self/peer assessment rubric; reflection essay; improvement plan; revised artifact	7
6. Dissemination & Civic Action	Information & data literacy (audience feedback); Communication & collaboration; Digital content creation (publishing); Safety (licensing/citizenship); Problem solving	Reflection/adaptation (transfer beyond the unit)	Published/presented artifact; licensing statement; audience feedback log; transfer reflection	6

Figure 1
Model-analytic coverage index across ESED phases



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Discussion

The ESED model responds to the need for STEAM designs that do more than incorporate technology superficially. By mapping learning phases to DigComp competence areas (Vuorikari et al., 2022) and to SRL strategies identified as effective in online and blended environments (Xu et al., 2023; Zhao et al., 2025), the model makes digital literacy and SRL teachable and assessable rather than assumed. Consistent with the design-product scope, the discussion interprets the model's design rationale and analytic alignment; it does not claim empirical effectiveness without classroom trials.

How Ethnophysics can Strengthen Digital Literacy and SRL?

Ethnophysics provides culturally meaningful problems that can raise task value and persistence, both of which support SRL. When students investigate a phenomenon from their community, they have reasons to set goals, seek information, manage effort, and persist through iterative design. Ethnophysics also invites responsible digital participation: students must document sources, consider the ethics of representing cultural practices, and decide how to publish artifacts respectfully. These routines align with digital competence expectations in information evaluation, communication, and safety.

How STEAM Workflows Support Competence Development?

STEAM projects naturally produce digital and physical artifacts that can evidence competence. Without conceptual scaffolding, students may prioritize product appearance. ESED addresses this by enforcing evidence checkpoints (data requirements, design criteria, iteration logs) so that each creative decision is connected to physics principles and measurable outcomes. This approach is consistent with STEAM reviews emphasizing structured inquiry and iterative critique (Deák & Kumar, 2024; Leavy et al., 2023).

A practical implication is that successful enactment depends on teacher capacity and classroom conditions. Teachers may need targeted professional development on (i) translating local phenomena into measurable physics investigations, (ii) managing interdisciplinary assessment with rubrics, and (iii) facilitating collaboration and feedback cycles. Time constraints, device/connectivity limitations, and large class sizes can reduce the frequency of checkpoints; therefore, ESED can be adapted by prioritizing a smaller set of high-leverage checkpoints (data quality, design rationale, and reflection) and by using low-cost/offline tools where needed.

SRL Scaffolding as Routine Classroom Culture

SRL is often treated as a learner trait, but evidence suggests SRL strategies can be cultivated through routines and interventions. Meta-analytic evidence highlights time management, effort regulation, metacognitive strategy, and organization as especially relevant in online/blended learning (Zhao et al., 2025). Accordingly, ESED embeds regulation artifacts: learning logs, role trackers, progress checkpoints, and reflection prompts. Teachers can gradually fade scaffolds as learners become more proficient, aligning with the goal of transfer beyond a single project.

Scaffold fading should be guided by evidence of readiness rather than a fixed schedule. For example, teachers can gradually reduce prompts when students consistently (a) set specific goals, (b) maintain design logs without reminders, (c) meet interim deadlines, and (d) use self- and peer-feedback to make justified revisions. Because SRL varies across learners, fading may need to be differentiated: some students may require continued supports for time management, help-seeking, or monitoring, especially in digitally demanding phases.

Digital Equity and Feasibility

School digital transformation literature emphasizes that the impact of technology is shaped by access, leadership, teacher competence, and institutional support (Timotheou et al., 2023). To increase feasibility, ESED is implementable with low-cost tools (smartphones, offline logs, basic spreadsheets) while still producing evidence of competence. When connectivity is limited, teachers can adopt an "offline-first" approach and stage publication through school exhibitions or delayed online sharing.

Implications for Teacher Education and Policy

Teacher education programs can use ESED as a planning and assessment scaffold. Pre-service and in-service teachers may use the phase map and assessment matrix to design culturally grounded STEAM projects, develop rubric literacy, and practice facilitation strategies for collaboration and critique. At the policy level, competence frameworks are sometimes adopted rhetorically; ESED offers a pathway for aligning classroom assessment with competence expectations.

Conclusion

This article proposes the ESED (Ethnophysics-based STEAM model for digital literacy and SRL) model as a structured approach to integrate culturally grounded physics learning with interdisciplinary STEAM projects while explicitly targeting digital literacy (including foundational computer literacy) and self-regulated learning. The six-phase cycle, supported by mapping tools, an assessment matrix, and an illustrative unit plan, helps teachers design learning experiences where students investigate meaningful local phenomena, work with data, create digital products responsibly, and regulate their learning through planning, monitoring, and reflection. The model provides a replicable starting point for classroom innovation and for future empirical research aimed at strengthening 21st-century competencies in science education.

Limitations and Future Studies

This paper presents a design blueprint and operational tools; empirical validation requires classroom trials across diverse contexts. Future studies can test the model through (i) expert review for content validity (cultural authenticity, physics accuracy, and indicator relevance), (ii) feasibility pilots using design-based research cycles, and (iii) effectiveness studies such as quasi-experimental pre–post comparisons, mixed-method case studies, or cluster trials where feasible. Research should also examine implementation sustainability (teacher workload, professional development needs, and repeated use across semesters) and how schools' digital capacity shapes enactment. Longitudinal work is recommended to evaluate transfer of digital competence and SRL beyond a single project.

Conflict of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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