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Hypermodule Deep Learning Inquiry–Steam: A Theoretical Framework And Science Teachers' Perceptions In The Digital Era

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Inquiry
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Abstract

Low scientific literacy and limited collaborative learning practices remain persistent challenges in science education, particularly in digitally constrained contexts where technology integration is uneven. This study develops a theoretical framework of the Hypermodule Deep Learning Inquiry–STEAM by integrating deep learning pedagogy, inquiry-based learning, and STEAM education into a unified digital learning model, while examining science teachers' perceptions of its implementation. A qualitative, exploratory survey design involved 38 junior high school science teachers in Biak Numfor Regency, Papua, Indonesia. Data were collected through open-ended questionnaires and semi-structured interviews, and were analysed thematically using open, axial, and selective coding. Findings reveal that teachers perceive deep learning as meaningful and transferable learning, inquiry as fostering scientific reasoning, and STEAM as promoting creativity and collaboration; however, these approaches remain fragmented in classroom practice. The study contributes a conceptual hypermodule framework linking pedagogical constructs, digital learning features, and targeted outcomes related to scientific literacy and collaboration skills. Future research should empirically test the framework's effectiveness across diverse educational contexts and examine its impact on student learning outcomes through mixed-method or experimental designs.

1. INTRODUCTION

The rapid advancement of digital technology has fundamentally reshaped educational practices, particularly in how teachers design, deliver, and evaluate learning experiences. Digitalisation enables interactive, adaptive, and learner-centred environments aligned with 21st-century competencies such as critical thinking, collaboration, and problem-solving (Herlinawati et al., 2024; Voogt & Roblin, 2012; Trilling & Fadel, 2009). Despite these opportunities, science education continues to face persistent challenges, notably students' low levels of scientific literacy and limited collaborative skills, which are essential for addressing increasingly complex global and socio-scientific problems (Bybee, 2015; OECD, 2023). These conditions indicate that technological adoption alone is insufficient; pedagogical innovation is required to transform how scientific understanding is constructed in digital learning environments.

Recent educational discourse highlights deep learning pedagogy as an approach that promotes meaningful understanding through conceptual connection, reflection, and knowledge transfer rather than memorization (Fullan, M., & Langworthy, 2014; Sim & Hung, 2024). In science education, deep learning closely aligns with inquiry-based learning, which engages students in authentic scientific practices, including observation, problem formulation, investigation, and evidence-based reasoning (Kotsis, 2024; Pedaste et al., 2015). Together, these approaches support deeper conceptual engagement and scientific reasoning. However, empirical studies show that inquiry implementation often encounters practical and cognitive limitations, including constrained instructional time, uneven student readiness, and difficulties connecting investigations to real-world contexts (Johnston, 2024; Lazonder & Harmsen, 2016; Reiser et al., 2021). Moreover, inquiry's emphasis on scientific procedures may be insufficient to address the interdisciplinary creativity and collaborative innovation required in digitally mediated learning environments (Chiu et al., 2025; Herro & Quigley, 2017; Li & Schoenfeld, 2019).

To address these limitations, STEAM education has emerged as a cross-disciplinary framework integrating science, technology, engineering, the arts, and mathematics to foster creativity, contextual problem-solving, and collaborative design thinking (Herro & Quigley, 2017; Spyropoulou & Kameas, 2024). Research suggests that STEAM complements inquiry by expanding learning beyond scientific investigation toward innovation-oriented outcomes and authentic problem solving (Dillon & Wong, 2025; Filipe et al., 2024). The integration of inquiry and STEAM promises a balanced scientific understanding, creativity, and collaboration.

At the same time, interactive digital media such as hypermodules offer new possibilities for integrating pedagogy and technology through adaptive navigation, multimodal representation, and reflective learning pathways (Kahar et al., 2022; Sumarno et al., 2021). However, research exploring how hypermodules can systematically operationalize deep learning, inquiry processes, and STEAM integration into a coherent pedagogical architecture remains scarce. This gap reveals a critical need for a conceptual framework that not only connects these pedagogical constructs but also translates them into digital learning mechanisms that support scientific literacy and collaborative competencies.

Previous studies have extensively examined deep learning pedagogy, inquiry-based learning, and STEM/STEAM education as separate or partially integrated approaches to improving science learning outcomes. Research on deep learning highlights its role in fostering meaningful knowledge construction and transfer (Sim & Hung, 2024; Sobar et al., 2024), while inquiry-based learning has been shown to strengthen scientific reasoning through structured investigation processes (Kotsis, 2024; Zaskia et al., 2024). Similarly, STEAM integration has been widely promoted to enhance creativity, interdisciplinary problem solving, and collaboration skills in science education (Filipe et al., 2024; Herro & Quigley, 2017). In parallel, digital learning innovations have introduced interactive modules and adaptive learning environments that support student engagement and personalization (Fatihah et al., 2023; Sumarno et al., 2021).

Existing studies largely treat these approaches independently or integrate them only at the instructional strategy level, with limited attention to a coherent pedagogical digital design framework that systematically connects deep learning principles, inquiry processes, and STEAM integration within interactive digital learning environments. Moreover, research exploring how such integration can be operationalized through hypermodule-based learning, particularly in resource-constrained educational contexts, remains scarce. This gap indicates the need for a conceptual model that bridges pedagogical theory with digital learning architecture.

Responding to this gap, the present study proposes Hypermodule Deep Learning Inquiry–STEAM as an integrative model that connects pedagogical constructs with digital learning design. Specifically, this study aims to (1) formulate a theoretical framework integrating Hypermodule Deep Learning Inquiry STEAM for science learning and (2) explore science teachers' perceptions regarding its potential to enhance scientific literacy and collaboration skills in the digital era. By situating the framework within a resource-constrained educational context, this study contributes conceptual insights into pedagogically grounded digital innovation and offers implications for advancing equitable digital transformation in science education (Kemendikbudristek, 2022; UNESCO, 2023)

2. METHOD

The study employed a qualitative exploratory survey design grounded in a descriptive–phenomenological paradigm to investigate junior high school science teachers' perceptions, understandings, and lived experiences regarding the implementation of a deep learning inquiry-STEAM–based hypermodule within digital science learning contexts (Grave et al., 2022). The exploratory survey approach was operationalised as a qualitative inquiry, using structured open-ended questionnaires complemented by follow-up clarification questions to capture experiential meanings across diverse educational settings. Participants consisted of 38 purposively selected science teachers from Central Java, the Special Region of Yogyakarta, and Papua, representing five districts/cities chosen to reflect geographical, infrastructural, and socio-educational diversity. Selection criteria included (1) a minimum of three years of science teaching experience, (2) involvement in digital learning or STEM/STEAM activities, and (3) prior participation in professional development related to deep learning or innovative pedagogy.

Data were collected through validated open-ended questionnaires focusing on teachers' conceptual understanding of deep learning pedagogy, inquiry practices, STEAM integration, perceptions of digital hypermodules, implementation challenges, and professional support needs. Qualitative data analysis followed systematic stages of initial coding, category development, thematic integration, and narrative synthesis using a combined centrifugal and centripetal coding strategy (Breda et al., 2023; Herro & Quigley, 2017). Analytical rigour was ensured through peer debriefing, intercoder agreement checks, member checking with selected participants, and triangulation across regions. Ethical procedures included informed consent and confidentiality protection. This methodological framework aligns with qualitative, descriptive, and phenomenological approaches commonly applied in science education research to generate contextualised empirical insights into instructional innovation in Indonesian junior high schools.

This approach aligns with established descriptive and phenomenological qualitative methodologies in science education research, as documented in prior studies (Damayanti, 2023; Grave et al., 2022; Shofiya, 2020), thereby aiming to provide rich, contextual empirical insights into instructional design models for digital science learning in Indonesian junior high schools.

3. RESULTS AND DISCUSSION

The findings indicate that science teachers are currently positioned within a transitional phase of pedagogical transformation, in which innovative instructional paradigms are conceptually understood but not yet systematically integrated into digital learning ecosystems. Across responses, deep learning, inquiry-based learning, and STEAM education were recognised as meaningful approaches; however, their implementation remains fragmented. This condition forms the empirical basis for proposing the Hypermodule Deep Learning Inquiry–STEAM framework as an integrative instructional architecture for digital science education.

The theoretical integration emerging from this study connects pedagogical constructs, digital features, learning mechanisms, and intended learning outcomes into a unified system. The structural relationship among these elements is summarized in Table 1, which presents the construct–feature–mechanism–outcome alignment underlying the hypermodule design.

Table 1. Integration Map of Constructs–Features–Mechanisms–Target Outcomes

Pedagogical Constructs	**Digital Hypermodule Features**	**Learning Mechanisms**	**Target Outcomes**
Deep Learning	Meaningful learning objectives, authentic tasks, formative feedback, guided reflection, personalised learning pathways	Promote deep cognitive engagement through conceptual exploration, systematic reflection, and the transfer of knowledge to real-world contexts.	High cognitive engagement and meaningful knowledge transfer
Inquiry-Based Learning	Orientation–conceptualisation–investigation–conclusion phases, interactive digital worksheets, evidence logs, and virtual labs	Facilitate evidence-based scientific processes through independent collection, analysis, and interpretation of data.	Strengthening scientific practice and science literacy (explaining phenomena, evaluating investigations, interpreting data)
STEAM Education	Cross-disciplinary project studios, digital design/engineering tools, visual/audio communication media, digital calculators and plotting tools	Stimulate collaboration, creativity, and scientific communication by designing innovative solutions and products.	Creativity, solution design, and accountable scientific collaboration

As shown in Table 1, deep learning serves as the cognitive foundation, emphasising meaningful engagement, guided reflection, and knowledge transfer. Teachers largely interpreted deep learning as learning that moves beyond memorisation toward contextual application, confirming transformative learning perspectives emphasising conceptual restructuring (Fullan et al., 2018) and Mehta, J., & Fine (2019). Nevertheless, implementation challenges related to curriculum rigidity and instructional time suggest that deep learning requires structured learning environments that can sustain reflective cycles. The hypermodule addresses this need through adaptive pathways and formative feedback embedded within digital learning sequences.

Empirical findings further reveal that inquiry-based learning is the most familiar pedagogical practice among teachers, particularly through observation and experimentation activities. However, inquiry implementation tends to remain procedural rather than epistemic, often limited by resource constraints and uneven student readiness. Teachers' perceptions regarding deep learning practices and constraints are synthesised in Table 2, which illustrates dominant themes including contextual meaning-making, implementation barriers, and reflective assessment strategies.

Table 2. Summary of Codes and Frequency for Teacher Deep Learning Understanding

Code	**Subtheme**	**Frequency**	**Percentage**	**Example Quote**
A1.1	Meaningful Concepts in Context	22	57.9%	"Linking concepts and applications"
A1.2	Implementation Constraints	14	36.84%	"Curriculum time is insufficient"
A1.3	Strategy & Evaluation	18	47.36%	"Reflection and authentic tasks"

The data in Table 2 demonstrate that teachers conceptually support student-centred learning but face structural limitations that hinder deeper inquiry cycles. This finding aligns with Pedaste et al. (2015), who argue that inquiry becomes effective only when supported by iterative reflection and evidence-based reasoning. Within the proposed framework, the hypermodule extends inquiry pedagogy by embedding investigation stages into digitally scaffolded environments that support data documentation, interpretation, and reflection continuity.

Teachers' perceptions of STEAM integration reveal both pedagogical potential and competency gaps. Most participants viewed STEAM positively as an interdisciplinary approach that can contextualise science learning and enhance creativity. However, teachers reported difficulty designing authentic cross-disciplinary learning and assessing integrated outcomes. The distribution of perceptions and implementation challenges is presented in Table 3.

Table 3. Perceptions and Implementation of STEAM in Schools

Code	Subtheme	Frequency	Percentage	Example Quote
C1.1	Introduction to STEAM	24	63.15%	"Interdisciplinary approach"
C1.2	Project Integration Examples	18	47.36%	"Solar system model combining art and science"
C1.3	Competency Barriers	13	34.21%	"Lack of understanding of STEAM"

Table 3 illustrates teachers' perceptions of STEAM integration, including project examples such as the Solar System Model, reported by 47.36% of respondents. In this project, science concepts, such as planetary characteristics, orbital motion, and scale comparison, are integrated with artistic elements through model construction, visual design, colour symbolism, and spatial composition. Students design planetary models using creative materials while applying scientific reasoning to represent relative size, distance, and planetary features accurately. This integration enables students to translate abstract astronomical concepts into tangible representations, thereby strengthening conceptual understanding, creativity, and collaborative skills. Teachers observed that such projects increased student engagement, improved visualisation of complex concepts, and encouraged communication of scientific ideas through artistic media. Competency barriers (34.21%), particularly limited understanding of STEAM principles, indicate the need for structured pedagogical support to ensure that artistic activities function as epistemic tools rather than supplementary classroom tasks. This finding supports research emphasising interdisciplinary representation as a mediator of scientific reasoning and creativity (Herro & Quigley, 2017; Spyropoulou & Kameas, 2024). Competency barriers indicate that STEAM integration requires structured pedagogical scaffolding rather than isolated project activities.

The overall orchestration of deep learning, inquiry, and STEAM within a digital environment is conceptualised through the proposed framework illustrated in Figure 1, which synthesises empirical findings into a theoretical learning architecture.

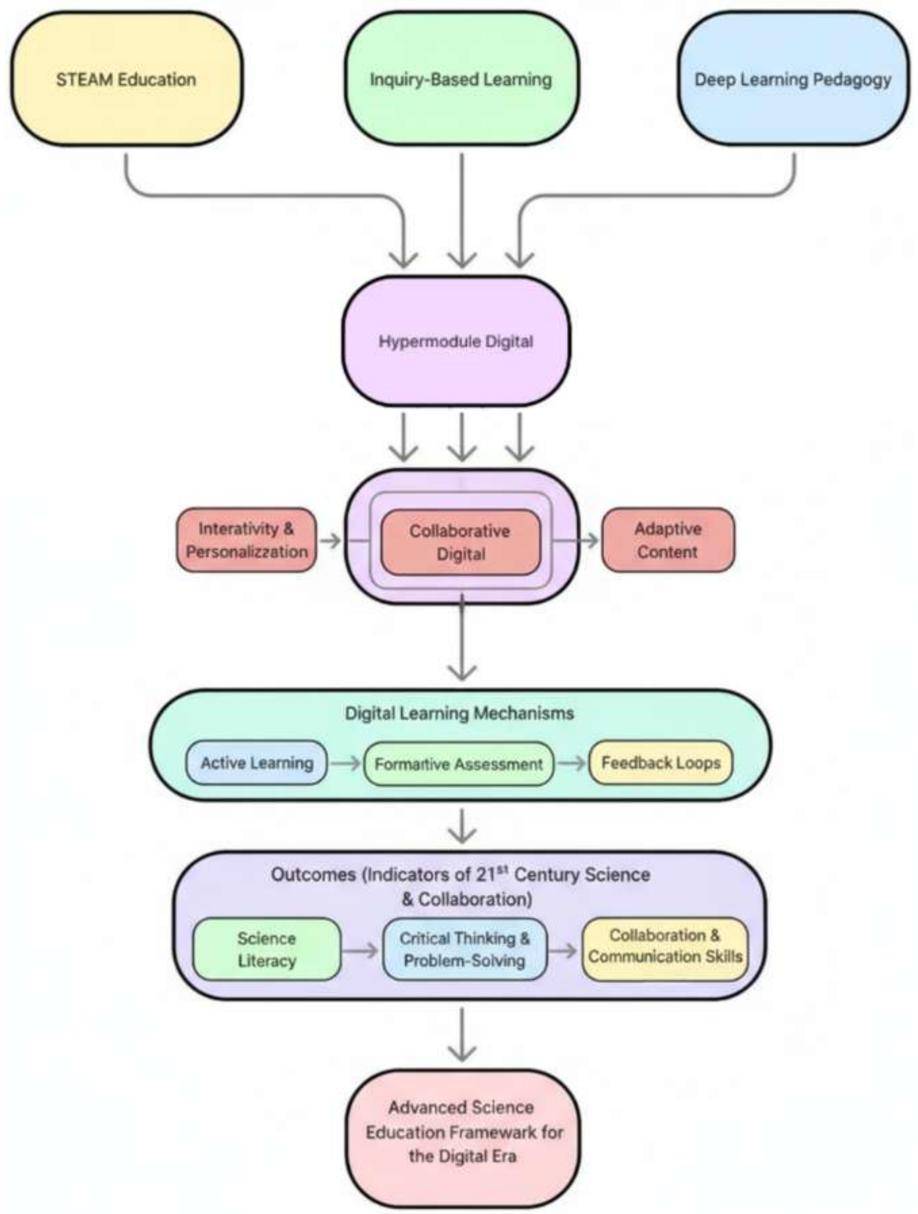

Figure 1. Theoretical Framework for the Integration of Deep Learning, Inquiry, and STEAM Hypermodule in Science Learning in the Digital Era

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Figure 1 demonstrates how cognitive engagement (deep learning), scientific processes (inquiry), and interdisciplinary creativity (STEAM) interact through hypermodule features to produce scientific literacy and collaborative competencies. Unlike previous models that treat these approaches separately, the framework positions digital environments as mediating systems that enable the simultaneous orchestration of reflective, investigative, and creative learning processes.

Despite strong pedagogical support, teachers emphasised infrastructural constraints that affect digital implementation. Challenges related to internet access, device availability, and institutional regulation are illustrated in Figure 2, which represents contextual barriers influencing hypermodule adoption.

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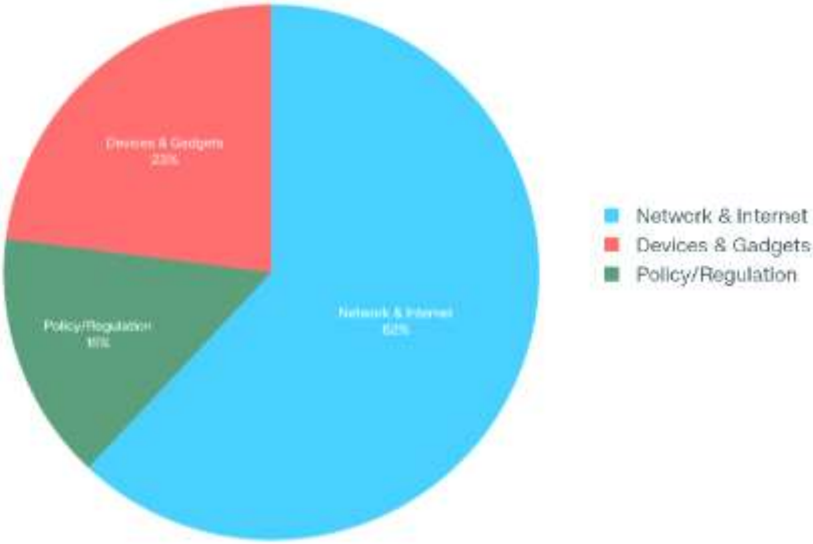

Figure 2. Infrastructure Constraints for Using Digital Modules

The data represented in Figure 2 indicate that technological inequality remains a decisive contextual factor, particularly in geographically remote regions. These findings reinforce global discussions on the digital divide, suggesting that technological innovation must be accompanied by equitable infrastructure and institutional support (OECD, 2023; Rilianti et al., 2023).

Teachers further highlighted that successful implementation depends not only on the availability of technology but also on professional readiness. Required forms of institutional support, including training, infrastructure provision, and policy reinforcement, are summarised in Table 4.

Table 4. Support Needed for Digital Transformation

Support	**Frequency**	**Percentage**	**Example Quote**
Teacher Training	29	76.32%	"Need digital training"
ICT Facilities & Infrastructure	32	84.21%	"Devices & network must be available"
School Policy	12	31.57%	"Need regulations for ICT utilisation"

As indicated in Table 4, teacher training emerged as the most urgent need, demonstrating that digital transformation is fundamentally pedagogical rather than technological. Teachers require support in integrating inquiry and STEAM principles into digital learning design rather than merely acquiring technical skills. This finding supports arguments that pedagogical digital competence determines the effectiveness of technology-enhanced learning (Fullan et al., 2018; White, 2023).

Synthesising all findings, this study advances the Hypermodule Deep Learning Inquiry–STEAM framework as a theoretical contribution that bridges three previously parallel pedagogical paradigms through digital mediation. The framework extends existing models by integrating cognitive depth, epistemic inquiry, and interdisciplinary creativity into a coherent instructional system supported by digital affordances. Consequently, hypermodules function not merely as learning media but also as pedagogical infrastructures that enable sustained scientific literacy development and collaborative learning.

From a practical perspective, the findings suggest that successful digital science learning requires alignment among pedagogy, technology, and institutional ecosystems. For future research, empirical validation through experimental or mixed-method studies is necessary to examine the framework's effectiveness across diverse educational contexts and its impact on scientific literacy, critical thinking, and collaboration outcomes.

4. CONCLUSION

This study confirms that science teachers demonstrate a strong conceptual understanding of deep learning, inquiry-based learning, and STEAM education, and hold positive perceptions of their integration through digital hypermodules. Nevertheless, a clear gap remains between pedagogical understanding and systematic classroom implementation due to limitations in digital infrastructure, technological competence, and institutional support. Addressing this gap, the study proposes the Hypermodule Deep Learning Inquiry STEAM framework as a conceptual contribution that integrates meaningful learning, scientific inquiry processes, and interdisciplinary collaboration within a unified digital learning environment. The framework advances existing pedagogical models by positioning hypermodules not merely as digital media but as pedagogical systems that facilitate reflective learning, evidence-based investigation, and collaborative problem solving to enhance scientific literacy and 21st-century skills. The findings imply the need for professional development focused on digital pedagogical design, strengthened institutional policies, and equitable access to technology. Future studies should empirically test the framework across diverse contexts to examine its effectiveness in improving students' scientific literacy, critical thinking, and collaboration in digital science education.

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