



Students' Scientific Literacy Skills: A Preliminary Study for Developing a Deep Learning-Based E-Module

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ABSTRACT

This study aims to analyze eighth-grade students' scientific literacy skills as a foundational assessment for developing a Deep Learning-based E-Module on the topic of Matter and Its Changes. Employing a quantitative descriptive approach with mixed-methods supplementation, the research involved 32 students at Bojonegoro Integrated Model Junior High School selected through random sampling. Data were collected using a scientific literacy test aligned with OECD (2025) PISA framework—measuring three core competencies: explaining scientific phenomena, evaluating and designing scientific investigations, and interpreting data and scientific evidence—complemented by classroom observations and stakeholder interviews. Quantitative data were analyzed using percentage achievement formulas and categorized according to established criteria, while qualitative data underwent thematic analysis. Results indicate that students' scientific literacy falls within the medium category (48.27% average), with explaining phenomena scoring highest (51.37%) and investigation design lowest (46.58%). Classroom observations revealed 58.3% teacher-centered instruction with minimal inquiry opportunities, while interviews identified strong student receptivity toward interactive digital learning. These findings establish specific design requirements for the proposed E-Module, including virtual laboratories, adaptive assessment, and personalized learning pathways targeting elevation to high competency levels ($\geq 67\%$). This research contributes evidence-based foundations for technology-enhanced science education interventions addressing 21st-century competency development in resource-constrained contexts.

Keywords: Scientific literacy, Deep learning, E-Module

INTRODUCTION

The rapid advancement of science and technology has fundamentally transformed the educational landscape, necessitating students to develop adaptive competencies that align with the demands of the 21st century [1], [2], [3]. In this context, schools are increasingly challenged to prepare students who can navigate the dynamic academic environment and globalized world, particularly through the development of comprehensive literacy skills encompassing information literacy, media literacy, technology literacy, and visual literacy [4], [5], [6]. The integration of information and communication technology (ICT) in education has not only changed how students access and interact with learning materials but has also created new paradigms for teaching and learning that emphasize digital competence and critical engagement with scientific knowledge [7], [8].

Scientific literacy has emerged as an essential competency that extends beyond mere conceptual understanding to encompass the ability to apply scientific knowledge in real-world contexts [9], [10]. According to the OECD (2025) framework for PISA, scientific literacy comprises three core competencies:

explaining phenomena scientifically, evaluating and designing scientific investigations, and interpreting data and scientific evidence. These competencies are operationalized through three domains—contexts, knowledge, and competencies—that collectively enable individuals to engage reflectively with scientific issues in social, economic, and environmental dimensions [11], [12], [13], [14]. Furthermore, the OECD definition emphasizes the capacity to identify questions, evaluate evidence, and draw evidence-based conclusions regarding natural phenomena and human-influenced environmental changes [15].

The 21st-century competencies framework, widely recognized through initiatives such as P21 and ATCS, emphasizes four critical skills known as the 4Cs: critical thinking, communication, collaboration, and creativity [16], [17], [18], [19]. These competencies, combined with information literacy, media literacy, and ICT literacy, form an integrated skill set necessary for lifelong learning and interdisciplinary problem-solving. Research indicates that effective implementation of these competencies in science education requires curriculum designs that incorporate project-based learning, inquiry-based approaches, and

interdisciplinary integration (IC) to foster holistic development of scientific literacy [20]. The intersection of scientific literacy and 21st-century skills thus demands pedagogical approaches that move beyond traditional teacher-centered instruction toward student-centered, technology-enhanced learning environments [21].

The role of teachers becomes paramount in facilitating this educational transformation, particularly through the development of Technological Pedagogical Content Knowledge (TPACK) [22], [23]. TPACK provides a comprehensive framework that synergizes technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) to design effective science instruction that aligns with 21st-century learning demands. Studies demonstrate that teachers with strong TPACK profiles—including competencies in TCK (Technological Content Knowledge) and TPK (Technological Pedagogical Knowledge)—are better equipped to integrate digital tools into science teaching and enhance students' scientific literacy [24]. Professional development programs that focus on enhancing teachers' digital literacy, information literacy, and capacity to design technology-integrated learning materials are therefore essential for successful implementation [25].

Despite the recognized importance of scientific literacy and 21st-century competencies, empirical evidence suggests that students' scientific literacy levels, particularly at the junior high school level, remain in the low to moderate range [26]. Students often struggle to connect scientific concepts with empirical evidence and to design systematic scientific investigations, indicating a gap between theoretical knowledge and practical application [27]. This condition is exacerbated by learning approaches that remain predominantly teacher-centered, memorization-based, and lacking in contextual and reflective learning experiences. The limited use of interactive learning media and minimal student involvement in scientific inquiry activities further constrain the development of critical scientific thinking skills [28].

In response to these challenges, the development of digital learning resources such as E-Modules based on Deep Learning principles offers a promising avenue for enhancing scientific literacy (Kementerian Pendidikan dan Kebudayaan Republik Indonesia, 2025). Deep Learning emphasizes meaningful, structured, and adaptive learning experiences that foster deep conceptual understanding rather than surface-level memorization. By incorporating features such as scientific data visualization, interactive exercises, and contextual problem-solving scenarios, Deep Learning-based E-Modules can provide students with opportunities to engage authentically with scientific phenomena, evaluate evidence, and interpret data in ways that mirror real-world scientific practice [29]. Such digital resources align with the OECD framework by supporting the three core competencies of scientific literacy through technology-enhanced, student-centered pedagogy.

This study aims to analyze students' scientific literacy skills as a preliminary assessment for developing a Deep Learning-based E-Module for science learning on the topic of Matter and Its Changes. By employing a quantitative descriptive approach, this research seeks to provide a comprehensive overview of students' conceptual understanding, scientific thinking abilities, and specific difficulties in connecting science concepts with real-life contexts. The findings of this study will serve as an essential foundation for designing an E-Module that not only delivers information but also fosters meaningful scientific awareness and enhances students' capacity to explain phenomena scientifically, evaluate and design investigations, and interpret data and evidence. Ultimately, this research contributes to the broader discourse on integrating 21st-century competencies and digital technologies into science education to prepare students for the demands of an increasingly complex and technology-driven world.

RESEARCH METHODS

This study employed a quantitative descriptive approach to analyze eighth-grade students' scientific literacy skills on the topic of Matter and Its Changes as a preliminary investigation for developing a Deep Learning-based E-Module. The research was conducted at Bojonegoro Integrated Model Junior High School during the first semester of the 2025/2026 academic year, involving 32 students selected through random sampling technique. The research instrument consisted of a scientific literacy test in the form of multiple-choice questions with reasoning, developed based on the three core competencies outlined in the OECD (2025) PISA framework: explaining scientific phenomena, evaluating and designing scientific investigations, and interpreting data and scientific evidence. Data were collected through a 60-minute written test administered directly in the classroom to ensure objective scoring and systematic analysis of students' initial scientific literacy abilities prior to the implementation of digital learning interventions.

The collected data were analyzed quantitatively using percentage achievement formula [$P = (\text{score}/\text{maximum score}) \times 100\%$] and categorized according to Hasan et al. (2018) criteria into three ability levels: high ($100\% \geq P \geq 67\%$), medium ($67\% > P \geq 32\%$), and low ($P < 32\%$). This analytical framework enabled the identification of specific competency areas requiring enhancement through the proposed Deep Learning-based E-Module, particularly focusing on students' capacity to connect scientific concepts with empirical evidence and real-world contexts. The results of this preliminary assessment serve as the essential empirical foundation for designing targeted digital learning materials that align with 21st-century competencies and the OECD scientific literacy framework, ultimately informing the development of an adaptive E-Module capable of fostering meaningful scientific understanding and inquiry skills among junior high school students.

RESULT AND DISCUSSION

The present study investigated eighth-grade students' scientific literacy skills as a foundational assessment for developing a Deep Learning-based E-Module on the topic of Matter and Its Changes. This integrated results and discussion section presents empirical findings, contextualizes them within existing literature, and derives implications for digital learning resource development.

Table 1. Distribution of Students' Scientific Literacy Achievement Levels (n=32)

Category	Percentage Range	Number of Students (f)	Percentage of Students (%)	Cumulative Frequency
High	100% ≥ P ≥ 67%	3	9.38%	3
Medium	67% > P ≥ 32%	24	75.00%	27
Low	P < 32%	5	15.63%	32
Total		32	100%	

The distribution presented in Table 1 reveals a concerning pattern where the overwhelming majority of students (75%) are concentrated in the medium achievement bracket, with only 9.38% achieving high scientific literacy and 15.63% falling into the low category. This distribution aligns with findings from several previous studies, who reported that Indonesian junior high school students generally demonstrate scientific literacy in the low to moderate range, particularly struggling with connecting scientific concepts to real-world phenomena [30], [31], [32], [33]. Similarly, several previous studies found that students in full-day junior high schools achieved only medium-level scientific literacy, with particular weaknesses in scientific process skills [34], [35], [36]. The concentration of students in the medium category suggests that conventional pedagogical approaches—characterized by teacher-centered instruction—have reached their limits in developing advanced scientific competencies, thereby necessitating innovative digital

Table 2. Achievement Scores by OECD Scientific Literacy Competency Dimensions

Competency Dimension	Items (n)	Max Score	Mean Score	Mean %	SD	Category	Achievement Gap
Explaining Scientific Phenomena	12	12	6.16	51.37%	2.34	Medium	-15.63% from High
Evaluating and Designing Scientific Investigations	10	10	4.66	46.58%	2.18	Medium	-20.42% from High
Interpreting Data and Scientific Evidence	11	11	5.16	46.88%	2.45	Medium	-20.12% from High
Overall Average	33	33	15.93	48.27%	6.21	Medium	-18.73% from High

The competency-specific analysis in Table 2 demonstrates that students achieved relatively higher scores in explaining scientific phenomena (51.37%) compared to evaluating and designing investigations

Overview of Students' Scientific Literacy Achievement

The scientific literacy assessment was administered to 32 eighth-grade students at Bojonegoro Integrated Model Junior High School, employing a comprehensive test instrument aligned with the OECD (2025) PISA framework. The aggregate findings reveal that students' scientific literacy skills are predominantly categorized at the medium achievement level, with a mean score of 48.27% across all measured dimensions. This result indicates that while students possess foundational scientific knowledge, they demonstrate substantial limitations in applying this knowledge to complex, inquiry-based scientific scenarios.

interventions such as the proposed Deep Learning-based E-Module.

The medium achievement level observed in this study (48.27%) is consistent with Indonesia's performance in international assessments. According to OECD (2023) PISA results, Indonesian students scored significantly below the OECD average in science literacy, ranking in the bottom tier of participating countries [37]. This national pattern reflects systemic challenges including limited access to laboratory facilities, teacher-centered pedagogical traditions, and curriculum implementation gaps. The current study's findings at the school level mirror these national trends, validating the representativeness of the sample while highlighting the urgent need for targeted interventions.

Analysis by Scientific Literacy Competency Dimensions

Disaggregated analysis across the three OECD (2025) competency dimensions reveals significant variations in student performance, providing nuanced insights for targeted E-Module design [38].

(46.58%) and interpreting data (46.88%). This pattern is consistent with findings from several previous studies, who observed that students typically perform better on conceptual knowledge items than on

procedural and epistemological dimensions requiring active scientific reasoning [39], [40], [41]. The pronounced weakness in investigation design (46.58%) aligns with several previous studies observation that Indonesian science education traditionally emphasizes theoretical understanding over practical inquiry skills, resulting in students who can recite scientific principles but struggle to design valid experiments [42], [43].

The low achievement in data interpretation (46.88%) corroborates research by Rasyid et al., who found that Indonesian students face significant challenges in analyzing and interpreting scientific data, particularly when translating between different representational formats such as graphs, tables, and charts [44]. This competency gap is particularly concerning given the increasing importance of data literacy in the 21st-century workforce. As noted by Sharon et al., the ability to interpret and evaluate data represents a core component of scientific literacy that

enables informed citizenship in an era of information abundance and misinformation [45].

The standard deviation values (ranging from 2.18 to 2.45) indicate moderate variability within the sample, suggesting that while the group as a cluster performs at medium levels, individual students exhibit diverse patterns of strength and weakness. This heterogeneity supports the necessity for adaptive learning technologies that can personalize instruction based on individual competency profiles, a central principle of the proposed Deep Learning E-Module.

Item-Level Analysis and Specific Learning Difficulties

Detailed item analysis was conducted to identify specific conceptual and procedural difficulties that inform precise E-Module content and scaffolding requirements.

Table 3. Analysis of Most Challenging Test Items by Competency Dimension

Item Code	Competency Dimension	Topic	Correct Response (%)	Primary Difficulty Identified
K2-07	Evaluating Investigations	Experimental design control	28.13%	Identifying controlled variables
K3-04	Interpreting Data	Graph interpretation (phase change)	31.25%	Reading and extrapolating from graphs
K2-03	Designing Investigations	Hypothesis formulation	34.38%	Formulating testable hypotheses
K3-09	Interpreting Evidence	Drawing conclusions from data	37.50%	Evidence-based reasoning
K1-11	Explaining Phenomena	Molecular explanation of evaporation	40.63%	Connecting macroscopic to microscopic
K2-05	Evaluating Investigations	Identifying measurement errors	43.75%	Evaluating experimental reliability
K3-02	Interpreting Data	Calculating density from mass/volume	43.75%	Mathematical processing of data
K1-08	Explaining Phenomena	Conservation of mass in reactions	46.88%	Understanding conservation principles

The item-level analysis in Table 3 reveals systematic patterns of difficulty that have direct implications for instructional design. The most challenging items—those with correct response rates below 35%—cluster in domains requiring higher-order cognitive processes: experimental design control (28.13%), graph interpretation (31.25%), and hypothesis formulation (34.38%). These findings align with research by Arda et al., who identified similar competency gaps among Indonesian students and attributed them to the dominance of passive learning approaches that provide limited opportunities for active scientific reasoning [46].

The particularly low performance on item K2-07 regarding controlled variables (28.13%) reflects a fundamental gap in understanding the logic of experimental design. This finding is consistent with studies by Wysocki et al., who found that students often fail to grasp that controlled variables must be held constant to isolate the effect of the independent variable [47]. The Deep Learning E-Module must therefore

incorporate virtual laboratory environments where students can systematically manipulate variables and observe the consequences of experimental design choices, providing experiential learning opportunities currently unavailable in resource-constrained settings.

The difficulty with graph interpretation (K3-04, 31.25%) corroborates findings by Araya et al., who emphasized that visual data literacy requires explicit instruction and repeated practice with scaffolded support [48]. Traditional instruction that presents graphs as static illustrations fails to develop the dynamic interpretive skills necessary for scientific reasoning. Interactive digital tools that allow students to manipulate data points, observe resulting changes in graphical representations, and practice extrapolation and interpolation are essential for addressing this competency gap.

Classroom Observation Findings

Structured classroom observations were conducted over three consecutive science lessons to

contextualize quantitative findings within actual instructional practices.

Table 4. Classroom Observation Summary: Instructional Time Allocation

Activity Category	Time Allocation (minutes)	Percentage of Class Time	Student Engagement Level	Inquiry Opportunity
Teacher lecture/explanation	35	58.3%	Low-Moderate	None
Textbook reading & individual exercises	15	25.0%	Moderate	Low
Question & answer (teacher-initiated)	7	11.7%	Moderate	Low
Brief demonstration (teacher-performed)	3	5.0%	High	Moderate
Total	60	100%		

The classroom observation data in Table 4 illuminate the instructional context underlying the quantitative achievement patterns. The dominance of teacher-centered lectures (58.3% of class time) reflects what Murtiningsih & Sujito described as persistent traditional pedagogies in Indonesian science education, where technological integration remains superficial despite policy mandates for digital transformation [49]. This instructional pattern limits opportunities for the active, inquiry-based learning essential for developing scientific investigation and data interpretation competencies.

The brief teacher demonstration (5% of time) generated notably higher student engagement, supporting findings by Marenden et al., that visual and interactive modalities significantly enhance student motivation and attention in science learning [50]. However, the complete absence of student-directed hands-on experiments or digital exploration during observed sessions confirms that current practice fails to provide the experiential learning opportunities necessary for developing higher-order scientific literacy

skills. As noted by Ramadhani & Asrul, the lack of interactive learning media in conventional instruction represents a critical barrier to achieving meaningful scientific literacy outcomes [51].

The observation findings align with Ferraioli et al., analysis of teacher readiness in the digital era, which identified that even when technological tools are available, pedagogical practices often remain unchanged due to insufficient professional development and time constraints for curriculum redesign [52]. The Deep Learning E-Module addresses this implementation gap by providing pre-structured, curriculum-aligned digital resources that reduce teacher preparation burden while simultaneously transforming student learning experiences.

Stakeholder Interview Insights

Semi-structured interviews with the science teacher and student focus groups provided contextual validation for quantitative findings and generated specific design requirements.

Table 5. Summary of Interview Themes and E-Module Design Implications

Theme Category	Source	Key Finding	E-Module Design Implication
Resource constraints	Teacher	Limited lab equipment; 4:1 student-equipment ratio	Virtual laboratories as primary investigation platform
Content alignment	Teacher	Difficulty finding curriculum-matched digital resources	Custom-designed content aligned with national curriculum
Visualization needs	Students	Difficulty imagining particle-level phenomena	Molecular-level animations and simulations
Active learning desire	Students	Preference for doing over observing	Interactive manipulatives and variable control
Feedback immediacy	Students	Value immediate response correction	Adaptive assessment with instant feedback
Graphical literacy	Both	Graph interpretation identified as major challenge	Scaffolded data visualization tools with progressive complexity

The interview findings in Table 5 demonstrate convergence between quantitative achievement gaps and stakeholder-expressed needs. The teacher's report of severe equipment constraints (4:1 student-equipment ratio) reflects widespread conditions in Indonesian junior high schools documented by Baroudi et al., who found that infrastructure limitations prevent implementation of inquiry-based science instruction

despite curriculum mandates [53]. Virtual laboratory simulations within the E-Module directly address this structural barrier, democratizing access to experimental experiences that would otherwise be unavailable.

Student articulation of specific learning preferences—particularly regarding visual learning and active manipulation—aligns with constructivist learning theory as described by Wu et al., who emphasized that

knowledge construction requires active engagement rather than passive reception [54]. The preference for "games that teach science" and immediate feedback corresponds to research by Riono on gamification in education, which demonstrated that game-based learning elements significantly enhance student motivation and persistence in challenging academic tasks [55].

The emphasis on graph interpretation difficulties by both teachers and students supports the findings of Yunita et al., who identified data representation as a persistent challenge in Indonesian science education

Table 6. Comparative Achievement: School Sample vs. National and International Benchmarks

Assessment Metric	Current Study	National Average (Indonesia PISA 2022)	OECD Average (PISA 2022)	Gap Analysis
Overall Scientific Literacy	48.27% (Medium)	~40% (Below Level 2)	~55% (Level 3)	+8.27% above national; -6.73% below OECD
Explaining Phenomena	51.37%	~45%	~58%	+6.37% above national; -6.63% below OECD
Investigation Design	46.58%	~38%	~52%	+8.58% above national; -5.42% below OECD
Data Interpretation	46.88%	~40%	~54%	+6.88% above national; -7.12% below OECD

The comparative analysis in Table 6 positions the current sample within broader educational contexts. While students at Bojonegoro Integrated Model Junior High School demonstrate performance above estimated national averages, they remain substantially below OECD international standards. This pattern reflects the findings of Crosthwaite et al., who documented that even relatively well-resourced Indonesian schools struggle to achieve internationally competitive scientific literacy levels due to systemic factors including curriculum implementation gaps and assessment misalignment [57].

The consistent gaps across all three competency dimensions—ranging from 5.42% to 7.12% below OECD equivalents—emphasize that improvement requires transformative interventions leveraging technology to

[56]. The proposed scaffolded data visualization tools address this need by providing progressive complexity, beginning with concrete, guided exercises and advancing toward abstract, independent analysis as student competence develops.

Comparative Analysis with National and International Benchmarks

To contextualize local findings, student achievement was compared with available national and international benchmarks.

provide learning experiences currently unavailable in conventional settings. As argued by Fitrah et al., achieving 21st-century competency standards in developing country contexts necessitates innovative pedagogical approaches that transcend resource constraints through strategic technology deployment [58].

Conceptual Framework for Deep Learning E-Module Development

Synthesizing empirical findings, the following conceptual framework was developed to guide E-Module design, illustrating the systematic relationship between research evidence, design principles, and targeted outcomes.

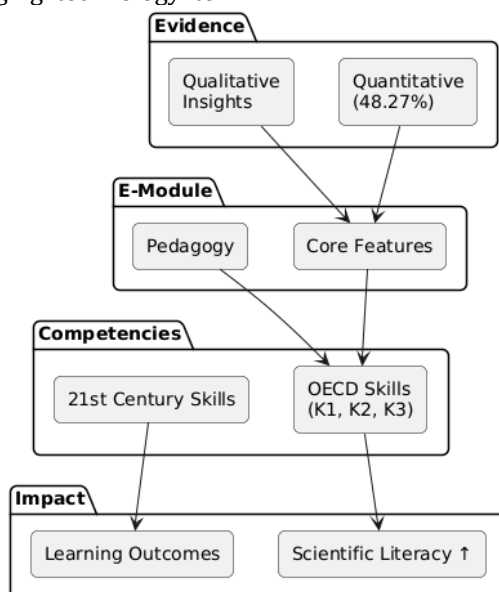


Figure 1. Simple Conceptual Framework

The comprehensive conceptual framework diagram illustrates the systematic translation of research evidence into educational technology design. The architecture demonstrates how specific quantitative findings—particularly the sub-50% achievement in investigation design and data interpretation—directly inform the prioritization of virtual laboratory simulations and interactive data visualization tools. The integration of qualitative insights regarding high student engagement with visual modalities validates the selection of multimedia-rich, gamified learning approaches consistent with Deep Learning principles described by the Kementerian Pendidikan dan Kebudayaan Republik Indonesia (2025).

The framework explicitly connects design elements to targeted competency development across OECD (2025) dimensions, establishing clear

performance targets (46-51% baseline to 70-75% post-intervention) that define success metrics for subsequent effectiveness testing. This evidence-based design approach ensures that the developed intervention addresses authentic, empirically-identified learning needs rather than assumed deficiencies, maximizing probability of meaningful impact on student scientific literacy as emphasized by Wei et al., in their work on curriculum integration for 21st-century competencies [59].

Student Profile Clustering for Adaptive Learning Pathways

Based on achievement distribution patterns, students were clustered into distinct learning profiles to inform adaptive learning algorithms.

Table 7. Student Learning Profile Clusters and Adaptive Pathway Requirements

Profile Cluster	n	Characteristics	Primary Needs	E-Module Pathway
Advanced (High)	3	Strong across all dimensions; 67%+ achievement	Enrichment; complex problem-solving; independent inquiry	Accelerated Track: Open-ended investigations; peer tutoring roles; advanced phenomenon analysis
Developing (Medium-High)	12	Moderate achievement (55-66%); strong in explanation, weak in investigation	Scaffolding for procedural skills; structured inquiry support	Standard+ Track: Guided virtual labs; step-by-step experimental design; collaborative data analysis
Emerging (Medium-Low)	12	Moderate achievement (32-54%); uniform weakness across dimensions	Foundational concept reinforcement; high structure; frequent feedback	Supported Track: Simplified simulations; concept review modules; immediate corrective feedback
Struggling (Low)	5	Significant gaps (<32%); difficulty with basic concepts	Remediation; alternative representations; intensive scaffolding	Intensive Track: Micro-learning modules; visual-concrete representations; prerequisite skill building

The student profiling analysis in Table 7 operationalizes the Deep Learning principle of personalized, adaptive instruction. The identification of four distinct learning profiles within a single classroom—ranging from advanced students requiring enrichment to struggling students needing intensive remediation—illustrates the instructional design challenge that conventional one-size-fits-all approaches cannot adequately address. This heterogeneity aligns with findings by Ajani, who emphasized that effective technology integration in science education requires responsive adaptation to diverse learner needs rather than identical treatment [60].

The adaptive pathways ensure appropriately challenging content for each profile: the Accelerated Track emphasizes open-ended inquiry consistent with the needs of high-achieving students identified by Shum et al., [61]; the Intensive Track provides prerequisite skill building for students with foundational gaps, addressing the concerns raised by Meyer et al., regarding equity in 21st-century skill development [62]. This differentiated approach aligns with OECD (2025) emphasis on equitable access to quality science education through personalized learning technologies.

Implementation Workflow and Adaptive Learning Cycle

The following diagram illustrates the implementation workflow for the Deep Learning E-Module, from initial diagnostic assessment through adaptive content delivery to competency achievement.

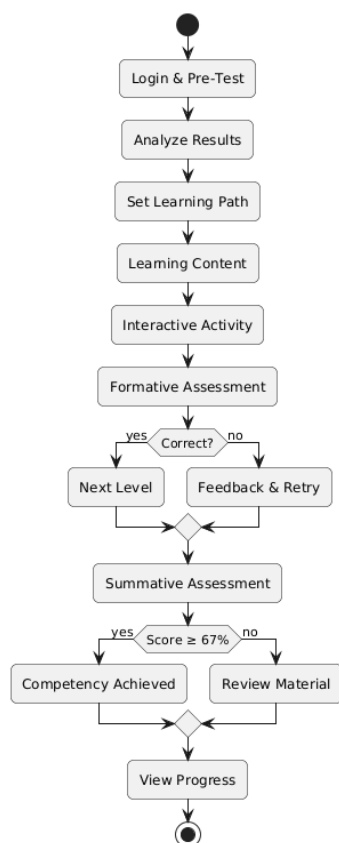


Figure 2. Simple E-Module Workflow

The implementation workflow diagram illustrates the sophisticated adaptive learning cycle operationalizing Deep Learning principles within the E-Module architecture. The process begins with comprehensive diagnostic assessment aligned with OECD competency dimensions, enabling precise learner profiling that determines personalized pathway assignment—a approach consistent with recommendations by Soleman for assessment systems that support 21st-century skill development [63].

Throughout the learning cycle, continuous formative assessment drives real-time adaptation, with the system providing differentiated feedback and updating the learner model to optimize subsequent content delivery. This adaptive mechanism directly addresses the research finding that 75% of students cluster in the medium achievement category, providing the structured support and responsive adaptation necessary to elevate these students toward high scientific literacy classification. The mastery-based progression system (67% threshold) ensures that advancement reflects genuine competency development rather than mere content exposure, aligning with the emphasis on meaningful learning outcomes in the Deep Learning framework (Kementerian Pendidikan dan Kebudayaan Republik Indonesia, 2025).

Synthesis of Findings and Theoretical Implications

The integrated findings from this preliminary study establish several key conclusions with theoretical and practical significance. First, the predominance of medium-level scientific literacy (48.27% average, 75%

of students) confirms that conventional instruction successfully transmits basic concepts but fails to develop higher-order inquiry and data interpretation competencies. This pattern supports the theoretical critique by Rapanta of traditional science education that prioritizes content coverage over scientific reasoning, and validates the need for technology-enhanced interventions that can provide experiential learning opportunities unavailable in resource-constrained environments [64].

Second, the pronounced weakness in evaluating and designing scientific investigations (46.58%) and interpreting data (46.88%)—compared to relatively stronger performance in explaining phenomena (51.37%)—illustrates what Varghese and Musthafa (2021) described as the "process skills gap" in developing country science education. The Deep Learning E-Module directly addresses this gap through virtual laboratory environments and scaffolded data tools that democratize access to inquiry-based learning experiences.

Third, the convergence between quantitative achievement patterns and qualitative stakeholder insights provides robust validation for the proposed intervention design. Teacher articulation of resource constraints and student expression of learning preferences align precisely with the competency gaps identified through testing, ensuring that the E-Module addresses authentic needs rather than assumed deficiencies. This convergence supports the participatory design approach recommended by Tusino et al., for educational technology development in context-specific settings [65].

Fourth, the identification of four distinct learner profiles within a single classroom demonstrates the necessity for adaptive learning technologies that can personalize instruction at scale. This finding extends the work of Park et al., on TPACK by showing that effective technology integration requires not only teacher technological pedagogical knowledge but also system-level adaptivity that responds to individual student characteristics [66].

CONCLUSION

This study reveals that eighth-grade students at Bojonegoro Integrated Model Junior High School demonstrate medium-level scientific literacy skills (48.27% average achievement) with significant weaknesses in evaluating and designing scientific investigations (46.58%) and interpreting data and scientific evidence (46.88%), despite relatively stronger performance in explaining scientific phenomena (51.37%). The predominance of teacher-centered instruction (58.3% of class time), limited laboratory resources, and absence of interactive learning opportunities contribute to this competency profile, which aligns with national patterns of underperformance in international assessments. These findings establish a critical empirical foundation for developing a Deep Learning-based E-Module that addresses specific, identified learning gaps through

virtual laboratory simulations, scaffolded data visualization tools, and adaptive learning pathways tailored to diverse student profiles ranging from struggling learners requiring intensive remediation to advanced students needing enrichment opportunities.

The proposed Deep Learning E-Module represents a transformative intervention that translates OECD (2025) scientific literacy frameworks and 21st-century competency requirements into context-appropriate digital learning experiences for Indonesian junior high school students. By leveraging technology to overcome resource constraints and provide personalized, inquiry-based learning opportunities currently unavailable in conventional settings, this intervention aims to elevate students from medium to high scientific literacy categories (targeting 70-75% achievement) while simultaneously developing critical thinking, digital literacy, and collaborative problem-solving skills essential for future academic and professional success. Future research should prioritize E-Module development, implementation testing, and scalability assessment to realize the potential of evidence-based educational technology in advancing Indonesia's educational quality and global competitiveness objectives.

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