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Learning Transformation in the Merdeka Belajar and Kampus Berdampak Era: Synergy of Technology, Pedagogy, and Digital Assessment

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Abstract: *The transformation of physics education in the Merdeka Belajar era represents a fundamental paradigm shift in how teachers and students perceive, construct, and apply scientific knowledge. This article presents a theoretical and reflective analysis of the integration of technology, pedagogy, and digital assessment within the context of Indonesian physics education. Using a narrative–reflective approach and a review of recent literature, the study articulates how the Technological Pedagogical and Content Knowledge (TPACK) framework serves as a conceptual foundation for building collaborative, flexible, and scientifically literate learning ecosystems. The findings suggest that the integration of digital tools—such as PhET interactive simulations and Tracker-based video analysis—enhances conceptual understanding, promotes critical thinking, and facilitates continuous formative assessment. Philosophically, Merdeka Belajar embodies not only curricular flexibility but also a humanistic vision of science education that nurtures empathy, social responsibility, and ecological awareness. Therefore, the transformation of physics education is not merely technological modernization but an epistemological reconstruction toward ethical, collaborative, and sustainable learning.*

Keywords: *digital assessment, merdeka belajar, reflective pedagogy, scientific literacy, TPACK*

Transformasi Kurikulum dan Pembelajaran Fisika di Era Merdeka Belajar dan Kampus Berdampak: Sinergi Teknologi, Pedagogi, dan Asesmen Digital

Abstrak: Transformasi pembelajaran fisika di era Merdeka Belajar mencerminkan perubahan paradigma mendasar dalam cara guru dan mahasiswa memahami, mengonstruksi, dan menerapkan pengetahuan ilmiah. Artikel ini merupakan kajian teoritik dan reflektif yang menelaah integrasi dimensi teknologi, pedagogi, dan asesmen digital dalam konteks pendidikan fisika di Indonesia. Melalui pendekatan naratif-reflektif dan studi literatur terkini, kajian ini menguraikan bagaimana model Technological Pedagogical and Content Knowledge (TPACK) dapat berperan sebagai kerangka konseptual untuk membangun ekosistem pembelajaran fisika yang kolaboratif, fleksibel, dan berorientasi literasi ilmiah. Hasil kajian menunjukkan bahwa integrasi teknologi digital—seperti simulasi interaktif PhET dan analisis video berbasis Tracker—dapat memperkuat konstruksi konsep, mendorong berpikir kritis, serta memfasilitasi asesmen formatif yang berkelanjutan. Secara filosofis, Merdeka Belajar tidak hanya mengusung fleksibilitas kurikulum, tetapi juga menegaskan pendidikan sains sebagai praktik humanistik yang menumbuhkan empati, tanggung jawab sosial, dan kesadaran ekologis. Dengan demikian, transformasi pendidikan fisika dipahami bukan sekadar modernisasi teknologi, tetapi rekonstruksi epistemologis menuju pembelajaran yang beretika, kolaboratif, dan berkelanjutan.

Kata kunci: asesmen digital, literasi sains, merdeka belajar, pedagogi reflektif, TPACK

INTRODUCTION

Over the past decade, Indonesia's higher-education system has entered a new phase of reform through the Merdeka Belajar – Kampus Berdampak (Freedom to Learn – Independent Campus) policy introduced by the Ministry of Education, Culture, Research, and Technology (Kemdikbudristek, 2020). The policy grants universities and students greater academic autonomy while demanding a learning paradigm that emphasizes exploration, flexibility, and relevance to real-world contexts. The Kampus Berdampak initiative does not replace the Merdeka Belajar philosophy but rather extends it. While Merdeka Belajar emphasizes freedom and autonomy in learning, Kampus Berdampak focuses on ensuring that this freedom produces measurable social, economic, and environmental contributions. In this sense, Kampus Berdampak represents the acceleration phase of Merdeka Belajar - from freedom to impact. This evolution highlights a policy shift from educational autonomy toward impactful engagement, positioning universities as active agents of societal transformation rather than mere providers of instruction. Within this framework, physics education must evolve from a knowledge-transmission model into a scientific inquiry-based, technology-enhanced learning process that nurtures curiosity, reflection, and critical thinking.

Physics, as a discipline, occupies a dual space between abstract theoretical reasoning and empirical observation. Traditional laboratory-based teaching often faces limitations of equipment, time, and safety, hindering students' ability to connect mathematical representations with physical phenomena. The emergence of digital learning technologies has begun to bridge this gap. For instance, PhET Interactive Simulations developed at the University of Colorado Boulder provide virtual experiments that visualize complex phenomena such as wave interference, photoelectric effect, and electric fields (Wieman et al., 2008). Similarly, Tracker Video Analysis enables students to collect, model, and interpret kinematic data from real-world videos, transforming their role from passive learners into active investigators (Brown & Cox, 2009).

This transformation aligns with global movements emphasizing scientific and digital literacy as core competencies of twenty-first-century education. The Organisation for Economic Co-operation and Development (OECD, 2021), through its Future of Education and Skills 2030 framework, identifies creativity, critical thinking, collaboration, and reflective learning as essential for preparing learners for a rapidly changing technological society. Likewise, the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2022) urges education systems to pursue a "new social contract" in which digital technology strengthens humanity and inclusion rather than replacing it.

Within this context, curriculum transformation in physics must extend beyond updating course content; it must also involve a reconstruction of epistemological and pedagogical foundations. The Technological Pedagogical and Content Knowledge (TPACK) framework proposed by Mishra and Koehler (2006) provides a comprehensive lens for integrating disciplinary knowledge (content), teaching strategies (pedagogy), and digital tools (technology). Through this lens, lecturers can design experiences that merge conceptual depth with meaningful digital engagement, enabling students to connect physics principles with everyday life and interdisciplinary applications.

Equally important is the transformation of assessment practices. Conventional examinations that emphasize factual recall need to be complemented by digital formative assessments that support ongoing feedback and reflective learning. Black and Wiliam (2009) demonstrated that formative assessment significantly enhances engagement and conceptual understanding when feedback is timely and dialogic. Digital platforms such as Learning Management Systems (LMS) or Google Classroom make such continuous feedback possible, allowing instructors to track student progress in real time and adjust pedagogical approaches responsively.

Consequently, the urgency of this reflective study lies in examining how the synergy of technology, pedagogy, and digital assessment can strengthen the transformation of physics education within the Merdeka Belajar era. The ultimate goal is not merely technological modernization but the cultivation of a humanistic and scientifically grounded learning culture that empowers students to think critically, act ethically, and adapt creatively to the challenges of the Society 5.0 era.

THEORETICAL

The transformation of physics education in the Merdeka Belajar era cannot be understood merely as a procedural or technological reform; it must be viewed as a philosophical and theoretical reconstruction of how learning, teaching, and knowledge creation are conceived. To explain this transformation comprehensively, it is necessary to establish a theoretical foundation that integrates educational philosophy, digital pedagogy, and the science of learning. The present study therefore adopts a conceptual framework grounded in three intersecting dimensions: the policy orientation of Merdeka Belajar, the TPACK model as a theory of digital pedagogy, and the broader context of curriculum transformation toward scientific and digital literacy. Together, these perspectives offer a holistic understanding of how technology, pedagogy, and assessment interact to redefine physics education for the twenty-first century.

The Paradigm of Merdeka Belajar in Physics Education

The Merdeka Belajar – Kampus Berdampak reform represents Indonesia's shift toward a more autonomous and learner-centered higher-education system (Kemdikbudristek, 2020). Within this framework, universities are encouraged to design flexible curricula that respond to social needs, technological advances, and the personal aspirations of students. For physics education, this means moving away from content-heavy instruction toward constructive and inquiry-based learning that allows students to develop their own understanding through exploration and reflection.

From a sociocultural perspective, Vygotsky (1978) emphasized that learning is a social process mediated by tools and interaction. In the context of digital education, technology becomes a mediating tool that enables collaborative meaning-making. When students engage in digitally supported inquiry, such as through virtual laboratories or online discussions, they operate within Vygotsky's "zone of proximal development," where guidance and peer interaction help internalize new concepts.

Global education frameworks reinforce this shift. The OECD (2021) advocates for learning environments that cultivate critical thinking, problem solving, creativity, and well-being. Likewise, UNESCO (2022) calls for a human-centered digital education in which technology strengthens equity and empathy. Thus, Merdeka Belajar aligns with international movements emphasizing lifelong learning, inclusion, and sustainability.

The Kampus Berdampak framework represents the continuation of the Merdeka Belajar philosophy with a stronger emphasis on measurable societal impact. Whereas Kampus Merdeka focused on learning flexibility and student mobility, Kampus Berdampak highlights higher education as a driver of transformation — encouraging universities to co-create innovation, sustainability, and community empowerment. This shift reflects a policy transition from academic autonomy toward responsible and outcome-oriented impact.

The TPACK Framework

The TPACK framework, proposed by Mishra and Koehler (2006), provides a comprehensive perspective on the knowledge base required by educators to effectively integrate technology in teaching. This framework emphasizes the interdependence between three domains of knowledge: content, pedagogy, and technology. In physics education, content knowledge refers to a deep understanding of physical principles, theories, and laws that form the foundation of scientific reasoning. Pedagogical knowledge encompasses the understanding of learning theories, instructional strategies, and classroom management approaches that foster meaningful engagement. Technological knowledge, meanwhile, involves the ability to select, operate, and critically evaluate digital tools to support learning objectives.

The intersection of these three domains forms the essence of digital pedagogy in modern physics education. When balanced effectively, TPACK enables educators to design learning experiences that seamlessly integrate theoretical understanding, experimentation, and technological visualization. Tools such as PhET Interactive Simulations and Tracker Video Analysis serve as exemplary instruments that connect technological affordances with pedagogical intent and disciplinary depth. These tools are not merely supplementary media. They function as epistemic instruments that transform abstract physics concepts into tangible and investigable phenomena, thereby deepening conceptual understanding and inquiry (Brown & Cox, 2009; Wieman et al., 2008).

Empirical evidence underscores the significance of this framework in enhancing educational practice. Laurillard (2012) conceptualized teaching as a design science, where educators employ technology to create iterative cycles of learning, feedback, and improvement. These insights affirm that digital pedagogy should not be viewed as a collection of isolated technical skills but as a reflective and adaptive process that continuously aligns the relationships between content, pedagogy, and technology. Through this integrative approach, physics educators can cultivate learning environments that are not only technologically sophisticated but also intellectually rigorous and pedagogically sound.

Curriculum Transformation toward Scientific and Digital Literacy

Modern curriculum reform emphasizes competency-based outcomes rather than mere content coverage. According to Redecker (2017), digital competence entails not only using technology but also evaluating, creating, and communicating knowledge responsibly. In physics, this translates into fostering students' ability to analyze data, interpret evidence, and apply physical reasoning to authentic problems.

The transformation toward Outcome-Based Education (OBE) requires that learning outcomes be measurable through both conceptual mastery and practical application. Project-based and inquiry-based approaches are therefore recommended. Virtual laboratories and simulations allow students to investigate variables, test hypotheses, and draw conclusions within safe and flexible environments. Through such processes, students develop scientific literacy—the capacity to understand and engage with science in personal, social, and technological contexts (OECD, 2021).

Digital formative assessment further supports this transformation. Black and Wiliam (2009) demonstrated that formative feedback enhances learning when it is continuous and specific. Tools such as online quizzes, digital rubrics, and reflective portfolios enable instructors to monitor students' conceptual progress dynamically. Consequently, assessment evolves from a judgmental act into a dialogue of learning, encouraging metacognition and self-regulation.

Overall, this theoretical framework positions the transformation of physics education as a multidimensional process integrating technology, pedagogy, and assessment to cultivate scientifically literate, digitally competent, and socially responsible learners for the Society 5.0 era.

METHOD

This study adopts a qualitative narrative-reflective approach designed to interpret, synthesize, and reflect upon the conceptual transformation of physics education within the framework of Merdeka Belajar. Rather than seeking statistical generalization, the narrative-reflective method emphasizes depth of understanding, interpretation of meaning, and integration of theoretical insights. It aligns with the view of Creswell (2013) and Merriam (2009) that qualitative research is appropriate when the aim is to explore how ideas and experiences are constructed within social and educational contexts. Accordingly, this study positions reflection not as a personal opinion but as a scholarly activity that integrates theory, policy, and practice.

The research process began with a systematic exploration of literature obtained from scholarly databases including Google Scholar, ScienceDirect, ERIC, and DOAJ. The selection focused on works that addressed transformation in physics or STEM education, digital pedagogy, assessment reform, and conceptual frameworks relevant to the Merdeka Belajar policy. Sources were restricted primarily to publications between 2010 and 2025 to maintain contemporary relevance, while foundational studies such as the TPACK model (Mishra & Koehler, 2006) and formative assessment theory (Black & Wiliam, 2009) were included for theoretical depth. Policy documents from the Ministry of Education and international institutions such as the OECD (2021) and UNESCO (2022) were also analyzed to contextualize the national reform within global educational discourse.

Data interpretation followed the reflexive thematic analysis model proposed by Braun and Clarke (2021). This analytical strategy involves identifying recurring ideas and constructing overarching themes that represent conceptual patterns across the literature. The process emphasized interpretive flexibility, allowing the researcher to identify connections between technology integration, pedagogical innovation, and assessment reform in physics education. Through iterative reading and reflection, three dominant themes were articulated: the transformation of curriculum under Merdeka Belajar, the role of TPACK in shaping digital pedagogy, and the importance of digital formative assessment in building scientific literacy. Each theme was examined in relation to both the theoretical framework and the broader philosophy of educational change.

The analysis culminated in a reflective synthesis that integrates the identified themes into a coherent conceptual understanding of how physics education is evolving in the Merdeka Belajar era. This synthesis was informed by the concept of the reflective practitioner, which explains how professional knowledge develops through continuous reflection in and on action (Schön, 1983). Ethical rigor was maintained by ensuring that all sources used were authentic, traceable, and accurately cited, while avoiding unverifiable references.

Ultimately, the narrative-reflective methodology serves not only as a means of analysis but also as an epistemological stance that recognizes knowledge construction as a dynamic and interpretive process. Through reflective reasoning and conceptual integration, this study seeks to articulate how educational transformation in physics emerges from the interplay of technological advancement, pedagogical philosophy, and assessment innovation.

RESULTS AND DISCUSSION

Reframing Physics Learning through Digital Inquiry

The results of the narrative-reflective analysis indicate that the transformation of physics learning under the Merdeka Belajar framework primarily emerges through a paradigm of digital inquiry. Traditional physics instruction, often limited to theoretical exposition, has been reoriented toward discovery-based activities facilitated by digital tools. Platforms such as PhET Interactive Simulations and Tracker Video Analysis have become central to this process, allowing students to visualize physical laws, manipulate variables, and observe dynamic results (Brown & Cox, 2009; Wieman et al., 2008). Through these platforms, students not only engage with fundamental concepts, such as Newtonian motion, harmonic oscillations, and electromagnetic induction, but also develop procedural understanding and data analysis skills essential for scientific reasoning.

This transformation aligns closely with constructivist learning theory, which views knowledge as actively constructed rather than passively received (Piaget, 1972; Vygotsky, 1978). In digitally supported inquiry, learners construct meaning by testing hypotheses, revising conceptual models, and connecting simulation outcomes to real-world phenomena. In a study by Sriyanti et al. (2020), the use of flipbook-based e-modules on transverse wave material produced a statistically significant improvement in student learning outcomes, with an N-gain value of 0.466 categorized as moderate. This finding provides empirical evidence that the integration of digital media and simulation tools meaningfully enhances students' conceptual understanding and engagement in inquiry-based physics learning. This aligns with the view of Tanrıverdi and Apak (2014), who found that teachers' curriculum orientations significantly influence their pedagogical decisions, a principle that resonates with the reflective and autonomous learning spirit of Merdeka Belajar. Within this model, Merdeka Belajar and Kampus Berdampak function together as pedagogical and philosophical frameworks, the former offering flexibility, the latter demanding meaningful outcomes and contributions.

The Role of Lecturers as Designers of Digital Pedagogy

The reflective analysis further reveals a decisive shift in the professional identity of physics educators. Lecturers are now positioned as designers of learning ecosystems rather than mere transmitters of content. According to Laurillard (2012), teaching in the digital era constitutes a form of design science, where educators iteratively plan, test, and refine learning activities to optimize student understanding. In this capacity, lecturers must integrate disciplinary expertise with technological fluency and pedagogical creativity—an intersection articulated by the TPACK framework (Mishra & Koehler, 2006).

In practice, this transformation requires educators to design courses that balance conceptual rigor with experiential engagement. For instance, a physics lecturer may combine asynchronous lectures with simulation-based inquiry and synchronous reflection sessions. This blended model, supported by Garrison and Vaughan (2013), promotes a more interactive and collaborative learning environment in which students actively construct meaning. Consequently, digital pedagogy is not a supplementary skill but a core dimension of professional competence for twenty-first-century physics educators.

Digital Assessment as a Catalyst for Reflective Learning

One of the most profound outcomes of this transformation lies in the integration of digital formative assessment. Under the Merdeka Belajar philosophy, assessment is reconceptualized not as an endpoint but as an ongoing process of reflection, dialogue, and growth. Black and Wiliam (2009) emphasized that formative assessment promotes meaningful learning when students and teachers engage in continual feedback cycles. In the digital context, this process is amplified through online platforms such as LMS, Google Classroom, and Microsoft Teams, which facilitate real-time feedback and longitudinal monitoring of conceptual development.

Redecker's (2017) DigCompEdu framework underscores the strategic role of educators in interpreting assessment data to personalize instruction. Within digital learning environments, physics lecturers can employ diagnostic quizzes, e-portfolios, and simulation-based reports to trace cognitive progress. For example, a lecturer may use PhET simulations on wave interference to assess conceptual understanding dynamically by tracking student interactions and prompting metacognitive reflection. This transformation is consistent with Earl's (2013) conception of assessment as learning, wherein assessment becomes an act of metacognition—students reflecting upon their own understanding, identifying misconceptions, and self-correcting through guided feedback.

Furthermore, the digitalization of assessment has profound implications for equity. As noted by UNESCO (2022), digital platforms enable inclusive participation and flexible pacing, allowing students from diverse backgrounds to learn according to their individual contexts. However, this inclusivity requires careful design to prevent technological barriers from reinforcing inequalities. Hence, physics educators must develop assessment literacy that combines pedagogical sensitivity with ethical awareness to ensure fair and human-centered evaluation.

Toward a Human-Centered and Sustainable Digital Culture in Physics Education

The Beyond pedagogy and assessment, the transformation of physics education is deeply intertwined with broader socio-technological changes. The Merdeka Belajar vision positions education as an agent of national resilience in the face of the Society 5.0 era, where human and artificial intelligence coexist in symbiosis. In this context, physics education carries a dual mandate: to cultivate scientific literacy and to foster ethical digital citizenship. As Fullan (2020) asserts, genuine educational change demands cultural coherence that aligns technological innovation with shared moral purpose.

A human-centered digital culture in physics learning therefore emphasizes not only efficiency and innovation but also empathy, collaboration, and sustainability. The OECD (2021) and UNESCO (2022) frameworks both stress that technological advancement must serve humanity by promoting inclusiveness, critical inquiry, and environmental stewardship. For example, integrating climate-related physics simulations or energy-system modeling projects can help students apply scientific reasoning to societal challenges, thereby connecting the discipline to the Sustainable Development Goals (SDGs).

Such integration positions physics as a living discipline that nurtures responsible global citizens capable of using scientific knowledge for social transformation. Digital pedagogy, when grounded in reflective practice and ethical commitment, becomes a medium through which students internalize not only how to analyze natural phenomena but also how to engage responsibly with the human and ecological consequences of scientific innovation. Thus, the transformation of physics education under Merdeka Belajar culminates in a moral and epistemological renewal—an education that blends analytical precision with compassion, curiosity, and civic consciousness.

CONCLUSION AND SUGGESTIONS

The transformation of physics education in the Merdeka Belajar era reflects a redefinition of how science learning is understood and practiced. It shifts physics learning from the transmission of established facts to the co-construction of meaning through digital, collaborative, and reflective experiences. This transformation supports a learning vision that is flexible, inclusive, human-centered, and oriented toward social and ecological responsibility.

Merdeka Belajar positions learners as autonomous explorers and educators as facilitators of inquiry and reflection. Within this framework, physics instruction becomes an evolving practice that balances scientific rigor, digital creativity, and pedagogical innovation. Simulations such as PhET and tools such as Tracker Video Analysis help make invisible physical processes observable. These tools support higher-order reasoning, experimental curiosity, data interpretation, and collaborative meaning-making. The transition from Kampus Merdeka to Kampus Berdampak also strengthens the role of higher education in producing real societal impact through science, technology, and education.

This paradigm also redefines assessment as a dialogical and formative process. Digital formative assessment places evaluation within the learning process by enabling continuous feedback, supporting conceptual understanding, and promoting self-regulated learning. Assessment therefore functions as a dynamic instrument for identifying misconceptions, scaffolding student thinking, and improving the quality of physics instruction.

Institutionally, the transformation of physics education requires more than technological resources. It requires a culture of trust, autonomy, reflective professionalism, and shared commitment to educational improvement. Universities need to support lecturers in developing digital pedagogical competence, designing inquiry-based learning, and using assessment data to improve student learning. This transformation should be understood as a long-term process of cultural development within higher education.

At a philosophical level, this transformation restores the human dimension of science education. Physics is a disciplined way of exploring and understanding reality through reasoning, evidence, and imagination. The Merdeka Belajar movement strengthens the connection between knowledge, technology, and humanity. It encourages physics education to cultivate learners who can think critically, act responsibly, and contribute wisely to a sustainable and just society.

Implications

The conceptual synthesis presented in this study carries several implications for the future of physics education, both in Indonesia and internationally. Theoretically, this study shows that educational innovation must be grounded in pedagogical philosophy and reflective design, rather than technological adoption alone. The integration of technology, pedagogy, and content becomes an important foundation for transformative physics learning. This implies that teacher education programs must place digital competence as a core dimension of professional formation. Educators must learn to view technology as a tool for thinking, inquiry, and reflection, not merely as a medium for delivering information.

Pedagogically, this transformation demands a redefinition of the lecturer’s role from information provider to learning architect. Lecturers need to design learning experiences that encourage inquiry, experimentation, collaboration, and reflection. Digital pedagogy should be developed through continuous refinement based on evidence, feedback, and classroom experience. Institutions should therefore foster reflective teaching cultures where experimentation with digital tools is encouraged, evaluated, and systematically documented. The use of simulation software such as PhET or Tracker can provide authentic contexts for developing higher-order thinking, conceptual understanding, and scientific reasoning.

Institutionally, the Merdeka Belajar framework requires universities to cultivate hybrid learning ecosystems. Physical laboratories and digital simulations should be combined to improve accessibility, inclusivity, and student engagement. Assessment practices must also evolve toward continuous, feedback-based systems supported by digital analytics. Such human-centered and flexible learning environments are essential for nurturing creativity, resilience, and lifelong learning. From a policy perspective, systemic reform must ensure that autonomy in learning is balanced with equity and quality assurance. Institutional trust, mentorship, and professional development should become the foundation of sustainable educational transformation.

Recommendations

Based on the findings of this reflective study, several recommendations are proposed to strengthen the ongoing transformation of physics education in Indonesia.

First, higher-education institutions should prioritize professional development that focuses on pedagogical design, not merely technological proficiency. Workshops and continuous training grounded in the TPACK framework can help lecturers integrate simulation-based and inquiry-oriented activities into physics courses. These programs should also promote collaboration among educators, enabling them to share digital lesson plans, reflect on outcomes, and collectively refine their practices.

Second, universities should establish interdisciplinary innovation hubs that connect education, physics, and information technology departments. These hubs can develop locally relevant virtual laboratory modules and open-access repositories, providing equitable access to digital resources across regions. This initiative can support a more inclusive digital learning ecosystem and reduce gaps in access to learning technology.

Third, policy stakeholders should institutionalize ethical and inclusive digital learning policies. Bridging the digital divide between urban and rural areas is imperative to achieving the democratization of education envisioned by Merdeka Belajar. This includes providing adequate technological infrastructure, ensuring fair access to connectivity, and embedding digital ethics—covering data privacy, artificial intelligence use, and academic integrity—into teacher education curricula.

Finally, future researchers are encouraged to empirically test the conceptual propositions advanced in this study. Mixed-method and longitudinal research could evaluate how TPACK-based instruction and digital formative assessment impact students' conceptual understanding, motivation, and problem-solving abilities. Through continued inquiry, Indonesia's physics education community can contribute robust empirical evidence to global discourses on digital transformation, pedagogical innovation, and scientific literacy.

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