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LEARNING MEDIA AS SOCIAL ARTEFACTS: HOW AESTHETIC DESIGN AND CULTURAL RELEVANCE SHAPE SELF-EFFICACY AND PERCEIVED APPLIED PHYSICS LITERACY IN INDONESIAN MINING ENGINEERING EDUCATION

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ABSTRACT

Aim/Purpose	This paper examines how learning media function as social artefacts that influence academic self-efficacy and perceived applied physics literacy, and addresses the need to understand the role of aesthetic design and cultural relevance in vocational STEM education.
Background	While interactive and visually appealing media are widely used, their combined impact with culturally relevant content on students' confidence and students' perceived disciplinary literacy remains underexplored, particularly in Indonesian Mining Engineering education.
Methodology	A cross-sectional survey was conducted among 355 undergraduate students in Mining and Geological Engineering programs. Data were analysed using Partial Least Squares Structural Equation Modeling (PLS-SEM) to test direct and mediating relationships among aesthetic design, cultural relevance, media interactivity, academic self-efficacy, and perceived applied physics literacy.
Contribution	This study integrates aesthetic, cultural, and functional features of learning media into a unified framework, offering empirical evidence of how these dimensions are associated with motivational and cognitive outcomes in applied STEM learning.

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Findings	Aesthetic design and cultural relevance were significantly associated with higher self-efficacy, which showed small but statistically significant indirect associations with perceived applied physics literacy. Media interactivity and usability were positively associated with students' perceived applied physics literacy but were not significantly associated with self-efficacy. Students' perceived applied physics literacy is therefore associated with both social (cultural and aesthetic) and functional (interactive) media features.
Recommendations for Practitioners	Educators and instructional designers should incorporate culturally aligned, aesthetically coherent, and interactive media to support students' self-efficacy and perceived disciplinary competence.
Recommendations for Researchers	Future studies should employ larger, diverse samples and mixed-method designs to explore how culturally and aesthetically informed media may support students' confidence, perceived disciplinary competence, and engagement with vocational STEM learning.
Impact on Society	By supporting students' confidence, perceived disciplinary competence, and engagement in vocational STEM learning, culturally and aesthetically informed media may enhance students' learning experiences in vocational STEM education.
Future Research	Investigate adaptive and AI-driven learning media that integrate cultural and aesthetic considerations to sustain engagement, identity formation, and self-efficacy across diverse educational contexts.

Keywords	aesthetic design, cultural relevance, self-efficacy, perceived applied physics literacy

INTRODUCTION

In contemporary higher education, learning media are not merely technical instruments for content delivery but social artifacts that reflect cultural values, professional identities, and institutional priorities. Within vocational and applied STEM education, such as mining-related programs, learning environments play a crucial role in shaping how students perceive their place within both academic and professional communities. Aesthetic coherence, cultural relevance, and media interactivity are associated with cognitive engagement, as well as students' confidence, sense of belonging, and identity formation as future professionals. From a social-scientific perspective, academic self-efficacy and students' perceptions of disciplinary literacy are socially situated outcomes, constructed through interactions between learners, cultural contexts, and educational practices. However, empirical research rarely examines how the aesthetic and cultural dimensions of learning media function as mediators between educational design and students' readiness to participate meaningfully in applied scientific fields. Addressing this gap is essential for understanding how educational practices contribute to broader processes of socialization, professional formation, and societal change within technical education.

In recent years, the design of learning media has emphasized not only functional and pedagogical utility but also aesthetic appeal and cultural resonance, particularly in digital and STEM education. Interactive and visually coherent media, such as multimedia presentations, augmented reality, and virtual simulations, have been found to significantly enhance student engagement and learning outcomes by creating immersive, intuitively structured experiences (AlGerafi et al., 2023; Ortiz-Rojas et al., 2025). Simultaneously, systematic reviews underscore the transformative potential of digital integration and cross-cultural approaches in fostering inclusive and innovative learning environments (Khalid et al., 2024; Novitra et al., 2025). Beyond visual presentation alone, recent STEM education

research has increasingly emphasized motivationally adaptive learning media, including gamified and interactive environments tailored to learners' needs and contexts. For example, adaptive gamification approaches have been shown to strengthen student motivation and engagement in science education when game elements are aligned with learners' characteristics and instructional goals (Zourmpakis et al., 2023). These findings reinforce the broader argument that effective educational media design extends beyond technical usability to include motivational, contextual, and psychologically meaningful learning experiences.

Within technical and STEM disciplines, especially those with strong applied aspects, the role of aesthetic and cultural elements in media design remains underexplored. Although interactive multimedia tools have been shown to enhance academic performance through heightened engagement (Kuchynka et al., 2021), and immersive user experiences influence motivation and technology adoption (Diputra, Husin, Fadhilah, et al., 2025; Saleem et al., 2024), the literature rarely integrates aesthetic design, cultural framing, and usability into a unified conceptual model. While subject-specific self-efficacy models suggest that disciplinary context matters (Ferri & White, 2024), there remains a dearth of empirical research examining how media aesthetics and cultural alignment influence self-efficacy and literacy in applied physics, particularly within fields such as mining engineering.

Despite growing acknowledgment of the importance of media quality, both aesthetic and interactive, for learning, most research examines these facets separately (Ruf et al., 2022; Shapiro et al., 2025). There is a critical need for comprehensive studies that simultaneously address the aesthetic design of media (including visual coherence and imagery), its cultural relevance (contextual identity and professional alignment), and their combined influence on discipline-specific self-efficacy, such as in applied physics, as well as the ensuing effects on students' perceived applied physics literacy, encompassing both conceptual understanding and perceived problem-solving ability. Technical fields shaped by industry-specific cultural identities, such as mining engineering, have been largely overlooked in investigations into how visually appealing and culturally aligned media can facilitate student learning. Without such integrated insight, we lack a framework for understanding how holistic media design bridges cultural identity, affective confidence, and perceived technical competence (Song et al., 2024).

This study fills that gap by presenting an integrated Structural Equation Modeling (SEM) analysis of how Aesthetic Design of Learning Media (ADM) and Cultural Relevance & Identity Alignment (CR), alongside Media Interactivity & Usability (MIU), predict Academic Self-Efficacy in Applied Physics (ASE) and Perceived Applied Physics Literacy (PAPL) among undergraduate mining engineering students. We propose a model in which ADM, CR, and MIU positively predict ASE and PAPL, while ASE functions as a mediator within the proposed structural relationships. By embedding aesthetic and cultural dimensions within a robust SEM framework, this research advances the theoretical discourse on aesthetic pedagogy in technical education. It offers empirical evidence that thoughtfully designed media may be associated with students' motivational perceptions and perceived learning experiences in STEM contexts.

LITERATURE REVIEW

AESTHETIC DESIGN OF LEARNING MEDIA (ADM)

Recent scholarship highlights that aesthetic characteristics of educational media (visual harmony, composition, clarity of visual hierarchy, and expressive imagery) meaningfully influence learners' attention, emotional engagement, and perceived credibility of materials. Studies in digital aesthetics demonstrate that the careful use of multimedia integrating images, typography, and motion can enhance engagement and facilitate comprehension when elements are coherent and purposeful, rather than decorative (Tham, 2025; Yildirim & Arefi, 2024). Research on sustainability and aesthetic communication also suggests that visual clarity and emotionally durable design foster a more profound user attachment to instructional artifacts, which, in turn, supports sustained use and learning opportunities (Granato et al., 2022). Taken together, these findings suggest that aesthetic design is not

merely surface decoration but a pedagogically functional dimension of learning media that can scaffold cognitive and affective processes essential for mastering complex STEM topics.

Cultural Relevance & Identity Alignment (CR)

A growing body of work emphasizes the importance of culturally responsive content and context-specific examples as central to meaningful learning (Koukoulidis et al., 2024). The culturally relevant pedagogy and culturally responsive assessment literatures argue that aligning instructional examples, language/register, and portrayed professional identities with students' cultural and occupational contexts increases relevance, motivation, and the transferability of learning (Le Pichon et al., 2025; Patterson, 2025). Empirical studies demonstrate that when curricular materials incorporate local industry practices or community data, students are better able to relate abstract concepts to practical problems and develop a stronger sense of professional identity, an outcome significant in vocational and technical programs (Weiland & Williams, 2024). For domains like mining engineering, where industry norms, safety culture, and local practices profoundly shape daily work, media that reflect these realities can help bridge the gap between classroom knowledge and practical application in the workplace.

Media Interactivity & Usability (MIU)

Interactivity and usability are consistently identified as critical factors influencing how effectively learners engage with multimedia resources. Studies on online interactive teaching, live-streamed instruction, immersive learning environments, and interactive simulations have demonstrated that navigation ease, responsiveness across devices, clarity of feedback, and availability of help or error-tolerance mechanisms significantly affect learner satisfaction, engagement, and learning outcomes (Diputra, Husin, Muzer, et al., 2025; Huang et al., 2023). Recent research further highlights that well-designed interactive features, such as timely and specific feedback, intuitive user controls, and adaptive navigation, enhance formative learning processes and foster self-regulated learning behaviors (Al-Shamaileh et al., 2026; Wong et al., 2019). In applied STEM education, the fidelity of simulations and the transparency of controls are critical, ensuring that learner interactions both approximate real-world processes and remain pedagogically scaffolded.

Academic Self-Efficacy in Applied Physics (ASE)

Self-efficacy remains one of the strongest proximal predictors of students' persistence, strategy use, and performance in STEM learning (Paz-Baruch, 2025). Discipline-specific investigations in physics education demonstrate that students' confidence in solving problems and performing laboratory tasks predicts not only short-term achievement but also longer-term identity formation in the discipline (Whitcomb et al., 2023). Recent work in physics education research and physics pedagogy links course design, peer interaction, and departmental supports to trajectories of self-efficacy, suggesting that the learning environment, including the affordances of media, can bolster or hinder confidence (Goldstein, 2016; Husin et al., 2025). These studies underscore that self-efficacy is context-sensitive: interventions that enhance perceived competence in one setting (e.g., interactive simulations tied to real-world examples) can generalize to improved performance on domain tasks when appropriately scaffolded.

Perceived Applied Physics Literacy (PAPL)

In this study, perceived applied physics literacy refers to students' self-reported understanding of physics principles, their perceived ability to apply these principles in domain-specific contexts, and their confidence in scientific explanations and problem-solving related to applied physics. Perceived applied physics literacy is considered an important outcome in vocational STEM education because students' perceptions of their disciplinary understanding and competence can influence engagement, persistence, and learning-related behaviors (Shanta & Wells, 2022). Research in culturally grounded STEM education and authentic problem-based pedagogy suggests that learners develop a deeper understanding when they engage with real-world, context-rich problems, employ disciplinary practices

such as modelling, data analysis, and explanation, and receive feedback that connects theory to application (Herro et al., 2026). Other studies using ethnoscience-enhanced virtual simulations have shown meaningful improvements in learners' ability to generalize physics concepts to new, workplace-relevant scenarios, thereby enhancing perceived applied physics literacy (Pozo-Rico et al., 2024). Despite these insights, few studies have examined how the combined effects of aesthetic design, cultural relevance, and media interactivity jointly contribute to perceived applied physics literacy, leaving an important empirical gap in understanding how holistic media design supports students' perceptions of technical learning in real-world contexts.

Synthesis And Implications For the Current Model

Across the five literature strands, three interlinked themes emerge that underpin the rationale for our SEM framework. First, aesthetic design plays a significant pedagogical role by enhancing learner engagement and credibility, guiding attention, and supporting comprehension (Tao & Tao, 2024). Empirical research on e-learning usability and credibility underscores how visual appeal can scaffold learning (du Preez & Jacobs, 2025). Further studies on the *aesthetic–usability effect* reveal that aesthetically pleasing interfaces are often perceived as more intuitive, thereby promoting smoother cognitive processing (Reinhardt & Hurtienne, 2024). Second, cultural relevance enriches learning by anchoring abstract content within students' occupational and community contexts, thereby enhancing the meaningfulness and transfer of knowledge. Investigations into culturally responsive teaching (CRT) highlight how educational designs that reflect learners' identities bolster engagement and self-efficacy (Paulick et al., 2024). Third, interactivity and usability act as critical functional enablers, turning aesthetic and cultural design features into active learning experiences. Research on simulations indicates that timely feedback, intuitive controls, and ease of navigation significantly influence self-efficacy, engagement, and conceptual understanding in physics (Reginald, 2023). For example, reviews of PhET simulations provide strong evidence that these interactive tools improve conceptual understanding of physics in active learning environments.

While each of these relationships is supported empirically in isolation, integrated models that simultaneously test the influence of aesthetic design, cultural relevance, and interactivity, particularly in applied physics and vocational fields such as mining engineering, remain scarce. This synthesis motivates our structural model, in which ADM, CR, and MIU are treated as exogenous design features, ASE is modeled as a mediator, and PAPL is the distal outcome reflecting students' perceptions of their disciplinary understanding and ability to apply physics concepts.

Theoretical Framework

Educational research increasingly supports the idea that aesthetic design in learning media, featuring well-integrated visuals, a balanced layout, and aesthetically coherent interfaces, is associated with higher levels of student engagement, perceived credibility, and cognitive focus, that is, learners attending more deeply to the content (Jafarkhani et al., 2024). Cultural relevance, in turn, is associated with more meaningful learning experiences by embedding content within students' cultural and professional identities, thereby making abstract physics concepts feel more meaningful and boosting learners' sense of belonging and confidence (Choi et al., 2025). Meanwhile, media interactivity and usability, particularly through intuitive controls, seamless navigation, and prompt feedback, are strongly associated with higher levels of satisfaction, motivation, and self-regulated learning in STEM education (Delen et al., 2014).

At the heart of this framework lies academic self-efficacy in applied physics, a well-established predictor of student persistence, strategy use, and achievement (Komarraju & Nadler, 2013). Learners who feel capable are more likely to engage thoroughly, apply knowledge strategically, and excel in complex tasks. When media is aesthetically appealing, culturally tailored, and interactively designed, it is associated with a learning environment that may support self-efficacy. It may enhance students'

perceived applied physics literacy, defined as their self-reported understanding of core physics concepts, their perceived ability to apply them to domain-specific problems, and their confidence in explaining scientific phenomena and solving technical issues. Evidence suggests that media that combine design quality, contextual relevance, and practical interactivity can support students' perceptions of these literacies in STEM learning contexts.

Integrating these strands, our proposed structural model posits that aesthetic design, cultural relevance, and interactivity/usability predict perceived applied physics literacy and, through self-efficacy as a mediator, indirectly support it (Figure 1). This architecture aligns with current educational technology insights and remains underexplored in applied physics contexts, particularly those intertwined with local or professional cultures, such as mining engineering.

The framework posits the following relationships:

- H1–H3: ADM, CR, and MIU positively predict ASE.
- H4: ASE positively predicts PAPL.
- H5–H6: ADM and MIU positively predict PAPL.
- H7-H9: ASE is positively associated with the indirect relationships between ADM/CR/MIU and PAPL.

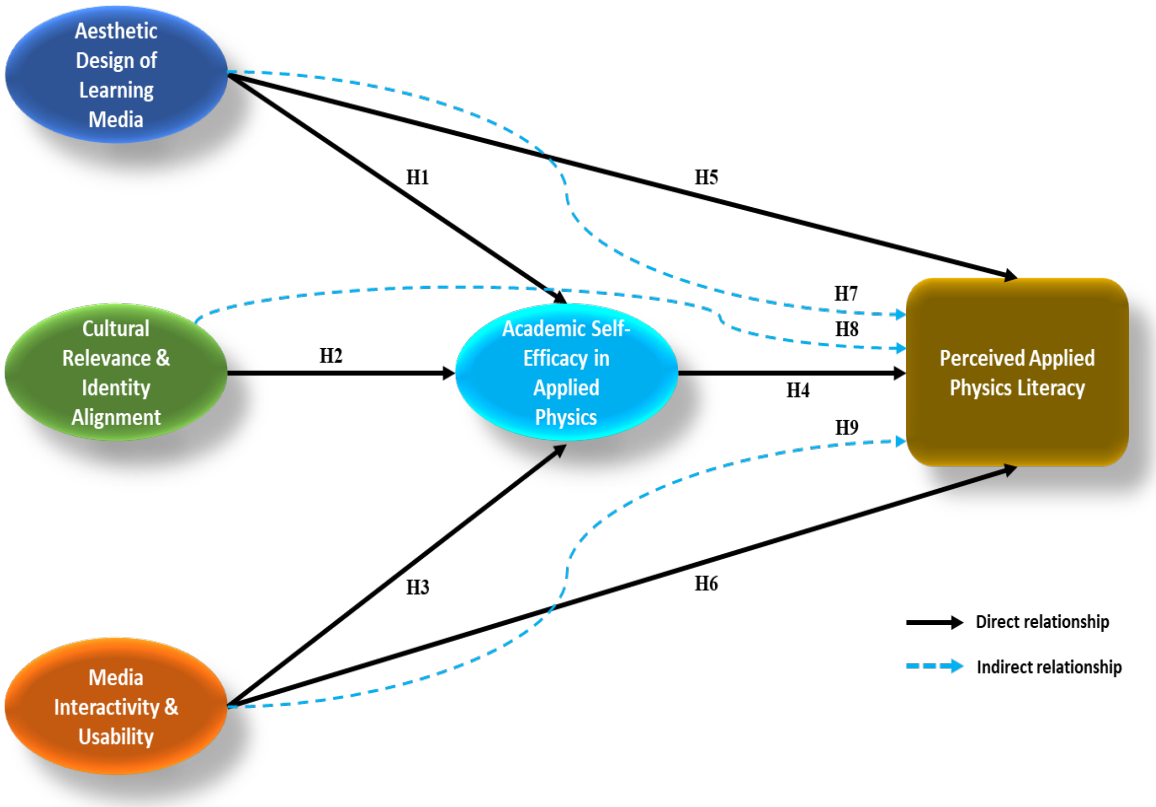

Figure 1. Model of theoretical framework

METHODOLOGY

RESEARCH DESIGN

Quantitative data were obtained through a cross-sectional survey and analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) (Oyewobi et al., 2025; Y. Wang et al., 2023). This

technique was selected because it effectively handles models with multiple latent constructs, allows for testing mediating relationships, and is particularly suitable for both predictive analysis and theoretical development in applied educational research (Hair & Alamer, 2022).

Population and Sample

Participants included students enrolled in Applied Physics courses within the Department of Mining Engineering, comprising the Mining Engineering undergraduate program, the Mining Engineering diploma program, and the Geological Engineering undergraduate program at a public engineering-focused higher education institution in Indonesia. Participants were recruited using convenience sampling based on course accessibility and voluntary participation during the data collection period.

Demographic information, including study program, gender, and entry year, was collected to describe participant characteristics. These variables were not included as control variables in the structural model because the primary objective of the study was to examine the theoretical relationships among the latent constructs rather than to examine demographic differences across student groups. Future studies may incorporate demographic and academic characteristics as control or moderating variables to examine potential variations in perceptions of learning media, self-efficacy, and perceived applied physics literacy across different student populations.

Data from 355 valid responses were collected for analysis. To ensure adequate statistical power for PLS-SEM estimation, an a priori power analysis was conducted using G*Power 3.1, following contemporary recommendations for structural equation modeling and multiple regression analysis (Faul et al., 2009; Hair & Alamer, 2022). Because the structural model contains a maximum of three predictors directed toward a single endogenous construct, the analysis was performed using a medium effect size ($f^2 = 0.15$), a significance level of $\alpha = 0.05$, and a statistical power level of 0.80. The GPower calculation indicated a minimum required sample size of 77 respondents. The final sample of 355 valid responses substantially exceeded this threshold, indicating adequate statistical power for estimating both direct and mediating effects within the proposed model.

Instrument Development

The questionnaire used in this study was developed specifically for this research through a multi-stage instrument development process grounded in the literature on educational technology, culturally responsive pedagogy, STEM self-efficacy, and disciplinary literacy. Because no existing instrument fully captured the integrated constructs examined in the context of applied physics learning in mining engineering education, the authors developed all measurement items based on theoretical definitions and recurring themes identified in prior empirical studies. The item generation process focused on ensuring alignment between the theoretical framework and the operational indicators representing aesthetic design, cultural relevance, media interactivity and usability, academic self-efficacy, and perceived applied physics literacy.

To establish content validity, the initial item pool was reviewed by three experts in STEM education, educational technology, and engineering pedagogy. The review process evaluated item clarity, contextual appropriateness, construct representativeness, and potential overlap among dimensions. Based on expert feedback, several items were revised or reworded to improve precision and reduce redundancy across constructs. Because the questionnaire was administered in Indonesian, the instrument underwent a translation and back-translation procedure to ensure semantic equivalence between the English and Indonesian versions. Minor linguistic modifications were subsequently made to improve readability and contextual suitability for mining engineering students. In addition, several procedural strategies were implemented to minimize common-method bias and generalized positive response tendencies. These included anonymous participation, counterbalanced item ordering, construct separation within the questionnaire layout, and the use of neutrally phrased statements to reduce evaluative response patterns.

The questionnaire measured five constructs: Aesthetic Design of Learning Media (ADM), Cultural Relevance & Identity Alignment (CR), Media Interactivity & Usability (MIU), Academic Self-Efficacy in Applied Physics (ASE), and Perceived Applied Physics Literacy (PAPL). The instrument was initially pilot tested with 40 mining engineering students to assess item clarity and preliminary psychometric properties. Because the construct was measured using self-reported questionnaire items rather than objective performance-based assessments, it should be interpreted as perceived applied physics literacy rather than demonstrated physics literacy. Accordingly, the findings reflect students' perceived understanding and perceived ability to apply physics concepts within mining-related contexts. The pilot test showed that all indicators had factor loadings above the 0.70 benchmark (ranging from 0.703 to 0.892), indicating acceptable item reliability. Construct reliability was also satisfactory, with composite reliability (CR) values ranging from 0.903 to 0.936 and Cronbach's alpha values between 0.874 and 0.921. Convergent validity was confirmed through AVE scores ranging from 0.653 to 0.742. Furthermore, discriminant validity was supported, as all Heterotrait–Monotrait (HTMT) ratios were below 0.85, demonstrating adequate distinction among constructs. Statistical checks were conducted to assess the potential influence of common-method bias in self-reported cross-sectional data.

In addition to procedural safeguards implemented during instrument design and administration, Harman's single-factor test indicated that the largest single factor accounted for 29.4% of the total variance, below the commonly referenced 50% threshold. Recognizing that Harman's test alone is a limited diagnostic approach, the study also employed a full collinearity assessment, following recommendations in PLS-SEM research. Full-collinearity VIF values ranged from 1.202 to 2.471, remaining well below the conservative threshold of 3.3, suggesting that severe common-method bias and multicollinearity were unlikely to substantially distort the estimated relationships among constructs. Nevertheless, because all variables were measured via self-reported responses collected from the same participants at a single point in time, some shared method variance may remain and should be considered when interpreting the findings. Table 1 presents the final measurement items for each construct, developed following expert review and pilot validation.

Table 1. Measurement items of the study constructs

Variable	Questionnaire item
ADM (Aesthetic Design of Learning Media)	ADM1: The learning media have a visually appealing layout that captures my attention.
	ADM2: The typography and graphical elements are consistent and clear.
	ADM3: The visual hierarchy effectively highlights key concepts.
	ADM4: Visual elements (images, icons, diagrams) support my understanding of physics concepts.
	ADM5: The overall aesthetic of the media feels polished and professional.
	ADM6: The design enhances my interest in the material.
	ADM7: The presentation feels well-structured and easy to follow.
CR (Cultural Relevance & Identity Alignment)	CR1: The media use examples related to mining practices that I can relate to.
	CR2: Language and terminology reflect the conventions used in mining engineering.
	CR3: The media portrays realistic professional scenarios from the mining industry.
	CR4: Content connects the physics taught to my future role as a mining engineer.
	CR5: The media acknowledges local or community aspects of mining.
	CR6: The content strengthens my sense of belonging to the profession.
	CR7: The examples provided help me link theory and real-world practice.

Variable	Questionnaire item
MIU (Media Interactivity & Usability)	MIU1: Navigational controls are intuitive and easy to use.
	MIU2: The media responds quickly on my device without lag.
	MIU3: Interactive simulations provide meaningful practice with clear outcomes.
	MIU4: Feedback is immediate and helps me understand what to improve.
	MIU5: The interface has helpful instructions or support when needed.
	MIU6: Controls (buttons, sliders) are easy to operate while learning.
	MIU7: I can easily move between sections or modules within the media.
ASE (Academic Self-Efficacy in Applied Physics)	ASE1: I am confident in solving applied physics problems presented in class.
	ASE2: I can perform physics experiments or practical tasks accurately.
	ASE3: I persist in problem-solving even when tasks are challenging.
	ASE4: I expect to eventually master the applied physics concepts.
	ASE5: I can apply physics knowledge during mining-related tasks.
	ASE6: I am confident in learning physics concepts independently.
	ASE7: I can systematically plan the steps to solve complex physics problems.
PAPL (Perceived Applied Physics Literacy)	PAPL1: I understand the core principles underlying the applied physics taught.
	PAPL2: I can apply these principles to real-world mining contexts.
	PAPL3: I can devise methods to solve technical problems using physics concepts.
	PAPL4: I can explain physical phenomena in a clear, scientific manner.
	PAPL5: I use data and evidence to support technical solutions.
	PAPL6: I can transfer learned physics concepts to new scenarios.
	PAPL7: I can communicate technical reasoning effectively to peers or instructors.

DATA ANALYSIS

All data analyses were performed in SmartPLS 4, adhering to conventional PLS-SEM workflows. Prior to model evaluation, the dataset underwent screening for missing values, outliers, and normality. All latent constructs in this study (ADM, CR, MIU, ASE, and PAPL) were specified as reflective measurement models because the indicators were conceptualized as manifestations of their underlying constructs, such that changes in the latent variables were expected to be reflected in changes across the observed indicators. Consistent with recommendations for reflective measurement models in PLS-SEM (Hair & Alamer, 2022), the measurement model was evaluated through assessments of indicator reliability (outer loadings), internal consistency reliability (Cronbach's alpha and composite reliability), convergent validity (average variance extracted), and discriminant validity (HTMT ratio).

The measurement model was then evaluated through several steps. Indicator reliability was confirmed using outer loadings; values above 0.70 were considered acceptable. Internal consistency was examined using both composite reliability (CR) and Cronbach's alpha. Convergent validity was established through Average Variance Extracted (AVE) values exceeding 0.50. In contrast, discriminant validity was assessed using the Heterotrait–Monotrait (HTMT) ratio; values below 0.85 indicate adequate construct separation (Cheung et al., 2024). Potential multicollinearity among indicators was also checked via both inner and outer VIF metrics.

The evaluation of the structural model involved analyzing the relationships among the latent variables. Path coefficients were calculated and their significance assessed using bootstrap resampling with

5,000 iterations to generate t-values and confidence intervals (Yang et al., 2025). The model's explanatory power was assessed using the coefficient of determination (R^2), with values of 0.75, 0.50, and 0.25 indicating substantial, moderate, and weak explanatory power, respectively (de Morais Fernandes et al., 2023; Kamranfar et al., 2023). Effect sizes (f^2) were calculated to assess the impact of each predictor, with thresholds of 0.02, 0.15, and 0.35 corresponding to small, medium, and large effect sizes, respectively (Fadhilah & Husin, 2023; Wall Emerson, 2023). Additionally, predictive relevance was evaluated using Q^2, where values above zero indicate predictive capability, and the same thresholds were applied to categorize the magnitude of predictive relevance. The mediation effects of ASE were examined using bootstrapping to analyze indirect effects and the ratio of indirect to total effects, determining whether mediation was partial or complete. All reporting adhered to contemporary PLS-SEM practice and followed guidelines for transparency and robustness as recommended by Hair and Alamer (2022) and Sarstedt et al. (2024).

Ethical Criteria of Research

This study followed institutional ethical guidelines for research involving human participants. The research was classified as minimal-risk educational survey research and, in accordance with institutional procedures applicable at the time of data collection, did not require formal ethics committee approval. Prior to participation, all respondents were informed of the study's purpose, the voluntary nature of participation, and their right to refuse or withdraw at any time without academic consequences. Informed consent was obtained from all participants before completing the questionnaire. To ensure confidentiality, no personally identifiable information was collected, and all responses were analyzed anonymously. Data were stored securely and used solely for research purposes. Because participants were recruited from courses within the department, additional safeguards were implemented to reduce potential coercion or perceived pressure, including clear separation between participation and course assessment, and explicit communication that non-participation would not affect grades or academic standing.

Results

As shown in Table 2, the study included 355 valid responses from students enrolled in three separate academic programs. The most significant proportion of participants came from the Mining Engineering undergraduate program (n = 155), followed by the Mining Engineering diploma program (n = 115) and the Geological Engineering undergraduate program (n = 85). Regarding entry year, 95 students were enrolled in 2024 and 260 in 2025, indicating that the majority of respondents were in their first year of study. Of the 355 participants, 73.52% were male (n = 261) and 26.48% were female (n = 94). This demographic profile highlights the male-dominated nature of engineering disciplines, particularly in fields such as mining and geology.

Table 2. Demographic characteristics of respondents

Variable	Category	n	%
Department of Mining Engineering	Mining Engineering (Bachelor's Degree)	155	43.66
	Geological Engineering (Bachelor's Degree)	85	23.94
	Mining Engineering (Diploma III)	115	32.39
Entry Year	2024	95	26.76
	2025	260	73.24
Gender	Male	261	73.52
	Female	94	26.48

MEASUREMENT MODEL

The measurement model was initially assessed to verify the reliability of indicators, internal consistency, convergent validity, and discriminant validity (Cheung et al., 2024). Outer loadings, Cronbach's alpha, CR, AVE, and VIF for each construct are presented in Table 3. All indicators exceeded the recommended minimum threshold of 0.70, confirming acceptable levels of reliability and validity. Discriminant validity was examined using the HTMT ratio, with values below 0.85 considered conservative and below 0.90 considered liberal, indicating satisfactory discriminant validity across constructs (Hair & Alamer, 2022). Detailed results are shown in Table 4.

Table 3. Measurement model: outer loadings, reliability, validity, and collinearity statistics

Construct	Indicator	Outer loadings	AVE	CA	CR	VIF
Aesthetic Design of Learning Media	ADM1	0.834	0.644	0.908	0.927	2.789
	ADM2	0.787				2.083
	ADM3	0.739				2.181
	ADM4	0.796				2.227
	ADM5	0.782				2.203
	ADM6	0.835				3.035
	ADM7	0.839				3.106
Cultural Relevance & Identity Alignment	CR1	0.777	0.621	0.897	0.919	2.059
	CR2	0.722				1.725
	CR3	0.724				1.797
	CR4	0.787				2.564
	CR5	0.808				2.711
	CR6	0.854				3.128
	CR7	0.833				3.251
Media Interactivity & Usability	MIU1	0.850	0.693	0.926	0.941	2.702
	MIU2	0.830				2.341
	MIU3	0.823				2.333
	MIU4	0.810				2.246
	MIU5	0.840				2.899
	MIU6	0.827				2.640
	MIU7	0.847				2.904
Academic Self-Efficacy in Applied Physics	ASE1	0.806	0.611	0.893	0.916	2.128
	ASE2	0.762				1.887
	ASE3	0.729				1.693
	ASE4	0.740				1.878
	ASE5	0.749				1.722
	ASE6	0.842				2.698
	ASE7	0.834				2.688
Perceived Applied Physics Literacy	PAPL1	0.879	0.732	0.939	0.950	3.137
	PAPL2	0.855				2.706
	PAPL3	0.874				3.093
	PAPL4	0.866				3.028
	PAPL5	0.846				2.922
	PAPL6	0.836				3.023
	PAPL7	0.833				3.002

Table 4. HTMT ratios for discriminant validity assessment

	ASE	ADM	PAPL	CR	MIU
ASE (Academic Self-Efficacy in Applied Physics)	-				
ADM (Aesthetic Design of Learning Media)	0.665	-			
PAPL (Perceived Applied Physics Literacy)	0.335	0.251	-		
CR (Cultural Relevance & Identity Alignment)	0.744	0.681	0.441	-	
MIU (Media Interactivity & Usability)	0.255	0.230	0.541	0.541	-

STRUCTURAL MODEL

Table 5 summarizes the findings of the structural model. The R^2 values show that the model explains just over half (51.4%) of the variation in Academic Self-Efficacy in Applied Physics (ASE). In comparison, it accounts for 30.4% of the variation in Perceived Applied Physics Literacy (PAPL), reflecting moderate and relatively modest explanatory strength (Hair & Alamer, 2022). The predictive relevance (Q^2) values for ASE (0.309) and PAPL (0.216) are both positive, indicating that the models have medium to extensive predictive capability. Regarding effect size (f^2), the paths CR → ASE (0.257), ADM → ASE (0.117), and MIU → PAPL (0.285) demonstrated medium effects. In contrast, the effects of ADM → PAPL (0.001), ASE → PAPL (0.031), and MIU → ASE (0.004) were negligible to small. These results highlight that Cultural Relevance & Identity Alignment (CR), Aesthetic Design of Learning Media (ADM), and Media Interactivity & Usability (MIU) show meaningful associations with ASE and PAPL, respectively.

Table 5. Coefficient of determination (R^2), predictive relevance (Q^2), and effect size (f2) of the structural model

Endogenous variable	R^2	Q^2	Predictor → Outcome	f^2
ASE (Academic Self-Efficacy in Applied Physics)	0.514	0.309	ADM→ASE	0.117
			CR→ASE	0.257
			MIU→ASE	0.004
PAPL (Perceived Applied Physics Literacy)	0.304	0.216	ADM→PAPL	0.001
			ASE→PAPL	0.031
			MIU→PAPL	0.285

The findings from the bootstrapping procedure are detailed in Table 6, which presents the path coefficients (β), t-statistics, and p-values for each hypothesized effect. The table also shows whether each hypothesis was confirmed or not. Several relationships were statistically significant at $p < 0.05$, while others did not reach significance. To enhance comprehension, Figure 2 illustrates the structural model with annotated path coefficients and significance levels, providing a clear visual representation of the relationships between the constructs.

Table 6. Path coefficients and hypothesis testing results

Hypothesis	Path coefficients	T-statistics	P-values	95% CI lower	95% CI upper	Decision
H1: ADM→ASE	0.309	5.512	0.000	0.190	0.427	Supported
H2: CR→ASE	0.500	7.540	0.000	0.362	0.631	Supported
H3: MIU→ASE	-0.051	1.265	0.206	-0.128	0.022	Not Supported
H4: ASE→PAPL	0.187	3.141	0.002	0.075	0.300	Supported

Hypothesis	Path coefficients	T-statistics	P-values	95% CI lower	95% CI upper	Decision
H5: ADM→PAPL	0.028	0.517	0.606	-0.077	0.134	Not Supported
H6: MIU→PAPL	0.462	9.746	0.000	0.369	0.550	Supported
H7: ADM→ASE→PAPL	0.058	2.723	0.007	0.023	0.107	Supported
H8: CR→ASE→PAPl	0.094	2.748	0.006	0.037	0.165	Supported
H9: MIU→ASE→PAPL	-0.010	1.159	0.247	-0.029	0.003	Not Supported

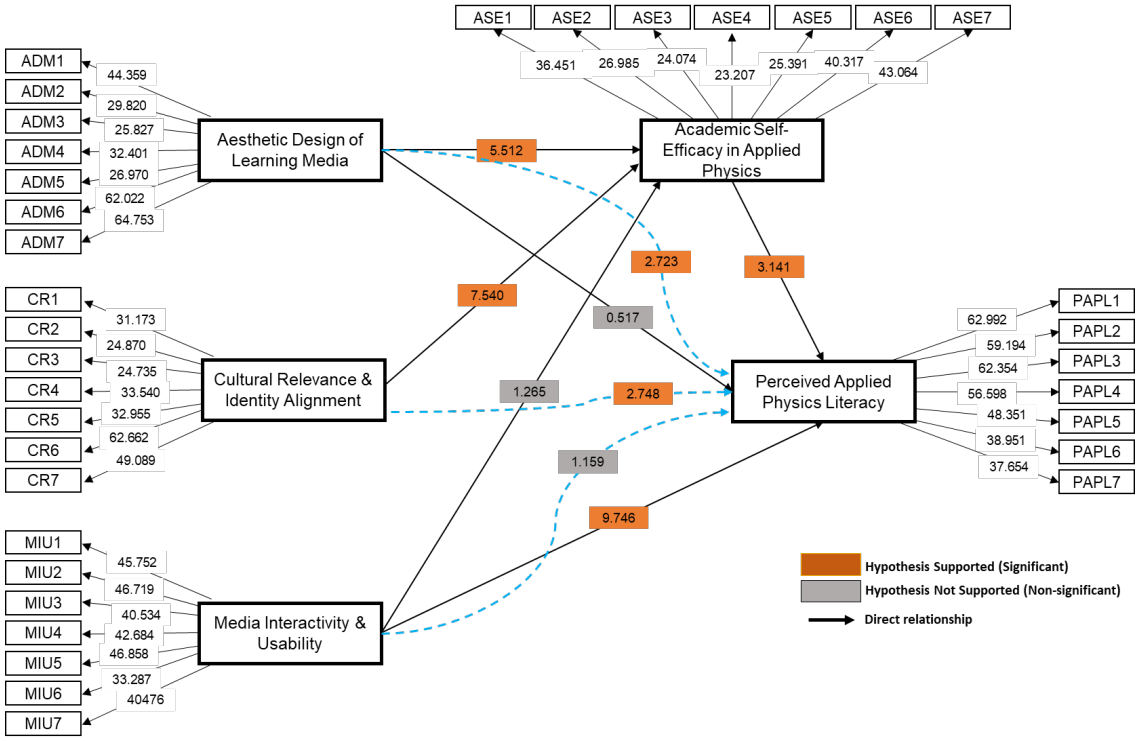

Figure 2. Structural model with path coefficients

DISCUSSION

ACADEMIC SELF-EFFICACY IN APPLIED PHYSICS

The findings suggest that the aesthetic design of learning media, along with its cultural relevance and alignment with identity, is positively associated with higher self-efficacy. When visual composition is coherent and compelling, learners report higher credibility and sustained attention, which may be associated with greater confidence in disciplinary tasks. Recent work in STEM and technology learning similarly frames aesthetics as more than ornamentation, positioning it as a catalyst for engagement. Research in STEM education suggests that integrating aesthetic design with narrative-based learning can enhance students' creative self-efficacy and improve their project performance, surpassing the outcomes of traditional project-based approaches (Husin et al., 2024; Mou, 2024). Research on the role of the arts and aesthetics in education highlights that aesthetic experiences have been associated with higher self-efficacy by enabling learners to conceptualize and turn ideas into reality, thereby reinforcing identity formation and intrinsic motivation (Pizzolante et al., 2024). Moreover, studies on attainment value and identity relevance in STEM show that when tasks are perceived as aligned with one's personal or cultural identity, students report higher self-efficacy, motivation, and persistence (Shankar & Robinson, 2024).

Equally, aligning media with learners' cultural and professional worlds appears to be associated with perceptions of legitimacy in the learning experience and to reinforce their sense of belonging, two well-established enablers of self-efficacy. Research shows that culturally responsive pedagogy, which incorporates learners' cultural backgrounds, familiar language, and authentic practices, is associated with greater academic confidence and a stronger sense of identity as capable participants in scientific disciplines. For example, the CECE model indicates that culturally relevant educational environments foster greater belonging, positive academic dispositions, and science self-efficacy among underrepresented students (Abrica et al., 2024). Research on multicultural education indicates that teachers with stronger multicultural skills tend to demonstrate greater confidence in managing culturally diverse classrooms, which, in turn, supports students' perceptions of their own competence (Taylor & Wendt, 2023).

Media interactivity and usability did not show a statistically significant association with academic self-efficacy in this sample. This suggests that, within the present data, interactive and usability features may not be directly related to students' confidence beliefs in applied physics. Several alternative interpretations are possible, including differences in prior experience with digital learning environments or variation in how students perceive feedback quality. However, these explanations remain speculative and should be interpreted cautiously, given the cross-sectional nature of the data.

Taken together, the pattern suggests that self-efficacy flourishes when learners engage with materials that are perceived as professionally credible and culturally resonant, or "for them." Moreover, interaction alone may not necessarily correspond with higher self-efficacy unless accompanied by meaningful feedback about progress and competence. Recent meta-analytic research indicates that students' perceptions of feedback from formative assessments play a significant role in shaping their self-efficacy and academic achievement, influencing outcomes both directly and indirectly through motivational processes (Qi et al., 2024). Additionally, in higher education contexts, students' self-efficacy significantly influences how they perceive the usefulness of instructor feedback and whether they actually use it in revising their work (Keller et al., 2024). These patterns align with broader trends in STEM and inclusive design frameworks, where self-efficacy and a sense of belonging interplay to support science identity, empowerment, and inclusive engagement.

Perceived Applied Physics Literacy

The results suggest that self-efficacy is positively associated with applied physics literacy, consistent with research indicating that learners with higher self-efficacy persist longer, employ more effective strategies, and perceive greater ability to transfer STEM concepts (Kuchynka et al., 2021). The immediate effects reveal a complementary story. Media interactivity and usability were significantly associated with perceived applied physics literacy, aligning with the literature that indicates interaction-rich, user-friendly content improves learning effectiveness and problem-solving (Langendorf & Khalid, 2025). Meta-analytical evidence further supports the idea that interactive and immersive modalities, notably augmented and virtual reality, enhance learning outcomes in science education (Koç & Kanadlı, 2025).

In contrast, aesthetic design does not show a direct relationship with literacy, although small indirect associations through self-efficacy were observed. These findings suggest that aesthetically coherent media may be associated with students' motivational perceptions, such as confidence and perceived credibility, rather than producing substantial improvements in their perceived applied physics literacy. Recent discussions of aesthetics in technology education illustrate this path, where the perceived quality of materials favors focus and a willingness to grapple with complexity rather than guaranteeing conceptual advantages on their own (Mou, 2024). Cultural relevance and identity alignment also showed small indirect associations with perceived literacy through self-efficacy. Contemporary literature on culturally responsive pedagogy suggests that when examples, scenarios, and language reflect future student communities and professions, students are more likely to associate abstract principles

with meaningful applications. These patterns are consistent with prior research suggesting that culturally relevant learning environments may be associated with greater confidence and perceived relevance, which in turn relate modestly to students' perceptions of literacy (Shankar & Robinson, 2024). Importantly, the observed effects are generally small in magnitude, suggesting that these relationships should be interpreted cautiously in terms of practical significance.

Media interactivity and usability do not exhibit an indirect contribution to literacy through self-efficacy. Although interactive features are directly associated with higher perceived comprehension and operate primarily in the cognitive domain, they do not inherently build learner confidence, which is essential for the affective pathway that supports literacy. Notably, in the context of technology-enhanced maker education, interactive peer-assessment approaches improved students' creative self-efficacy, highlighting that interactivity influences creative confidence only when coupled with reflective, socially mediated learning strategies. Yet, interactivity alone may not sustain self-competence (X.-M. Wang et al., 2024). Although several indirect effects reached statistical significance, their effect sizes were small, indicating limited practical magnitude. These findings suggest that aesthetic design and cultural relevance are associated with perceived applied physics literacy primarily through motivational pathways, but the strength of these associations remains modest. Accordingly, the results should be interpreted as indicative of weak associative relationships rather than strong substantive effects.

IMPLICATIONS

This study highlights that aesthetically coherent and culturally relevant learning media are associated with higher academic self-efficacy in applied physics, which in turn shows modest associations with students' perceived applied physics literacy. While interactive and usable media are positively associated with students' perceived literacy through cognitive engagement, these associations may be complemented by aesthetic and culturally relevant design features. For practitioners in technical and vocational STEM education, especially in mining and engineering contexts, these findings imply that instructional media should move beyond functionality and interactivity to incorporate design elements and contexts that resonate with students' cultural and professional identities. Integrating local industry practices, familiar language, and credible visual aesthetics may be associated with higher student confidence and stronger perceived understanding. At an institutional level, curriculum designers and policymakers should promote standards that balance aesthetic, cultural, and functional quality in digital learning resources to support students' confidence, perceived disciplinary competence, and engagement with vocational STEM learning.

LIMITATIONS, RECOMMENDATIONS, AND FUTURE DIRECTIONS

This study has several limitations that need to be considered. First, the study focused solely on engineering education and had a limited sample size, so the results cannot be generalized to other fields of study or more diverse populations. Furthermore, the approach used emphasized the analysis of relationships between variables without in-depth exploration of other external factors that could influence the results, such as differences in learning styles, more complex cultural backgrounds, and students' socio-economic conditions. Another limitation concerns the measurement of perceived applied physics literacy, which relies on self-reported questionnaire items rather than objective or performance-based assessments. Consequently, the findings should be interpreted as reflecting students' perceived applied physics literacy rather than demonstrated literacy or actual physics achievement. Future studies are encouraged to incorporate authentic assessments, problem-solving tests, or performance-based evaluations to provide a more direct measurement of applied physics literacy.

An additional limitation is reliance on self-reported cross-sectional data collected from the same respondents at a single point in time. Although procedural remedies and statistical assessments were implemented to reduce and evaluate common-method bias, including full-collinearity testing and

Harman's single-factor analysis, the possibility of shared method variance cannot be entirely eliminated. Consequently, some observed relationships among aesthetic perceptions, cultural relevance, self-efficacy, and perceived literacy may partially reflect common response tendencies or subjective evaluation patterns rather than fully independent effects. Future research is therefore encouraged to incorporate multi-source data, longitudinal designs, behavioral measures, or objective assessments to evaluate better the temporal ordering and potential causal relationships among the constructs.

Given these limitations, further research is recommended to expand the sample by involving a wider range of institutions and academic fields and to employ a mixed-methods design that enables more in-depth qualitative data collection. Such approaches may provide a more comprehensive understanding of how the aesthetics of learning media design and cultural appropriateness shape students' self-efficacy and physics literacy. Future research can also be directed toward developing more adaptive and inclusive learning models, for example, by utilizing interactive digital technology or artificial intelligence that considers cultural and aesthetic aspects, so that learning media is not only functional but also able to build emotional connectedness, identity, and self-confidence in students in a sustainable manner. Furthermore, because the study employed a cross-sectional survey design, the findings should be interpreted as associative rather than causal relationships among the constructs.

CONCLUSION

This study demonstrates that learning media design is associated with students' perceived confidence and perceived learning outcomes in applied physics. Aesthetic coherence and cultural relevance are positively associated with academic self-efficacy, while media interactivity and usability are more directly associated with perceived applied physics literacy. However, the observed effects are generally small, indicating that these relationships should be interpreted as modest associations rather than strong determinants of learning outcomes. In vocational and technical education contexts such as mining engineering, learning media that reflect students' professional context may support more meaningful learning experiences, primarily through motivational pathways. Nevertheless, the findings do not provide strong evidence for broader claims about identity formation or large-scale educational transformation. Instead, they highlight the importance of balancing functional and contextual design features in digital learning resources. Future research should further examine these relationships using longitudinal designs and performance-based measures to understand better their robustness and practical significance across different educational contexts.

DECLARATIONS

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- *Funding.* This study did not receive any financial support.
- *Data availability*. The datasets generated or analyzed during the current study are available from the corresponding author upon reasonable request.
- *Informed consent statement*. All participants were volunteers who were fully informed about the study's procedures and their rights, including the option to withdraw from the study at any time. Informed consent was obtained from all participants, and their personal information was protected; no personal data was collected or processed.
- *Institutional review board statement*. This study was carried out in accordance with all applicable legal requirements and institutional guidelines.

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