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Pentahelix Collaboration for Building Secondary School Teachers' AI-Enabled Digital Competence: A Case Study

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Keywords

Pentahelix model, digital competence, artificial intelligence in education, technology-enabled learning, secondary education, Indonesia

Abstract

This qualitative case study examines how Pentahelix collaboration—structured engagement among government, industry, academicians, community, and local mass media—addresses systemic barriers to AI adoption among 28 secondary school teachers (SETs) from 14 schools in Gresik Regency, Indonesia. Using a holistic single case-study design and guided by four research objectives, the study assessed AI utilisation levels, identified barriers, mapped stakeholder roles, and reconstructed a collaborative model. Findings reveal that most teachers (60%) reached only a moderate level of AI understanding, with persistent misconceptions and structural gaps in infrastructure, resources, and curriculum impeding integration. The Pentahelix model, which emerged inductively from observed collaboration patterns, fostered AI literacy, improved pedagogical integration, and built a sustainable multi-stakeholder support ecosystem. The findings carry critical implications for technology-enabled and blended learning for development, offering a replicable framework for policymakers seeking to scale AI adoption through collaborative governance.

Introduction

Despite AI's potential for personalised learning and adaptive pedagogy (Hwang et al., 2020; Zheng et al., 2023), it remains underutilised in secondary education systems in developing countries, where teachers face limited technical knowledge and inadequate institutional support (Kizilcec, 2023; McGrath et al., 2023; Ng et al., 2024). This study examines the *Bakti Pendidikan Saka 2023* programme in Gresik Regency, Indonesia, initiated by PT. Saka Indonesia Pangkah Limited (PT SIPL) under Regent Regulation No. 92/2021 (CSER), involving five Pentahelix actors: government, industry (PT SIPL), academicians, SETs—educators at SMA (Senior High School), SMK (Vocational High School), and MA (Islamic Senior High School) levels—and local mass media.

The central variables of this study are digital competence—the ability to effectively deploy digital tools, online platforms, and educational applications in pedagogically meaningful ways—and AI utilisation, i.e., the integration of AI-powered systems into classroom practice. Research establishes that digital competence forms the prerequisite for AI literacy, enabling teachers to critically understand, evaluate, and deploy intelligent systems in their pedagogy (Su

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et al., 2022; Zawacki-Richter et al., 2019). A comprehensive framework by Chiu et al. (2024) confirms that AI competency encompasses both AI literacy (knowing) and applied competence (confidently using in context). The conceptual framework guiding this study integrates three constructs: the Pentahelix model of multi-stakeholder collaboration, digital competence theory for educators, and AI utilisation in educational contexts.

Four research gaps informed this study: (a) Pentahelix models had not been applied to teacher AI professional development in the Global South (Hoerniasih et al., 2022; Yunas et al., 2023); (b) AI-in-education reviews focused predominantly on higher education in high-income countries (Chiu et al., 2023; Zawacki-Richter et al., 2019); (c) studies on teacher digital competence in Indonesia (Hidayat et al., 2023) had not examined multi-stakeholder collaboration; and (d) CSR-driven educational transformation programmes remained undocumented. This study addressed all four gaps through inductive Pentahelix reconstruction from secondary education field evidence.

Objectives

The study was guided by four objectives: (1) assess AI utilisation among SETs; (2) identify barriers to AI integration; (3) map Pentahelix actor roles; and (4) reconstruct a Pentahelix model for AI-enabled pedagogy.

Theoretical Framework

Pentahelix Model

The Pentahelix model is a collaborative governance framework involving five actor categories—government, business/industry, academicians, community, and mass media—to achieve inclusive and sustainable development through a shared vision and pooled resources (Yunas et al., 2023). An extension of the Triple Helix (university-industry-government) and Quadruple Helix (adding civil society) Models, the Pentahelix uniquely incorporates mass media as a strategic actor, adding societal legitimation to the collaboration architecture (Hoerniasih et al., 2022). In education, the model has been applied to address institutional challenges and improve innovation diffusion (Sulaeman et al., 2021). Its relevance here lies in its capacity to align resources, expertise, and public advocacy across sectors for systemic teacher competence development. The model's particular advantage for this study is that it was not applied deductively as a pre-selected framework but emerged inductively from the actual stakeholder structure observed in the field—a methodological choice that strengthens the authenticity of the findings. Prior applications of the Pentahelix in Indonesian education contexts confirmed the model's suitability for addressing complex, multi-dimensional challenges that exceed the capacity of any single institution (Sulaeman et al., 2021; Yunas et al., 2023), providing theoretical precedent for its application here.

Digital Competence and AI Literacy

Digital competence encompasses the ability to use digital tools, navigate online platforms, and integrate ICT to facilitate adaptive, meaningful learning experiences (Hidayat et al., 2023; Wang & Zhang, 2023). For educators, digital competence extends beyond hardware and software operation to include: designing learner-centred environments that leverage technology for differentiated instruction; supporting student critical thinking and collaborative skills through technology-mediated tasks; guiding responsible and ethical technology use; and continuously updating one's own technological knowledge through professional learning networks (Chohan & Hu, 2022; Dai, 2023; Zimmer & Matthews, 2022). Crucially, digital competence serves as the prerequisite for AI literacy—enabling teachers to understand AI system architectures at a

functional level, critically evaluate the pedagogical appropriateness of specific AI tools, and effectively deploy AI systems within curriculum-aligned instructional designs (Su et al., 2022; Zawacki-Richter et al., 2019). Without foundational digital competence, teachers cannot meaningfully adopt AI tools for instructional purposes; they lack the conceptual scaffolding to distinguish AI from non-AI digital tools, evaluate algorithmic recommendations critically, or adapt AI outputs for age-appropriate classroom use (Ayanwale et al., 2024; Hava & Babayiğit, 2024; Sperling et al., 2024; Tenberga, & Daniela, 2024). This makes digital competence development the necessary and non-negotiable first stage in any AI integration strategy, preceding tool-specific training. Research on Indonesian teachers specifically documents that digital competence levels remain uneven across school types and regions (Hidayat et al., 2023), with rural and Islamic school teachers consistently showing lower baseline scores—a pattern directly relevant to the Gresik sample studied here, where MA and rural SMK teachers demonstrated the lowest AI understanding levels. The rapid diffusion of generative AI tools such as ChatGPT has intensified this unevenness by creating new demands that precede existing training frameworks (Chiu et al., 2024).

AI Utilisation in Education

AI in education enables personalised and adaptive learning by tailoring content, pacing, and feedback to individual student needs, thereby improving educational outcomes (Haleem et al., 2022; Hwang et al., 2020). Tools such as ChatGPT, ClassPoint AI, and Assemblr Edu support 21st-century skill development and interactive content creation (Luan et al., 2020; Martín-Sómer et al., 2024). Systematic reviews of AI literacy in secondary schools confirm that such tools are increasingly integrated into K-12 pedagogical practice, though teacher preparedness remains the critical limiting factor (Ng et al., 2024). For SETs to leverage these capabilities, they must develop digital competencies for tool evaluation, curriculum alignment, and AI-assisted formative assessment (Chiu et al., 2023; Khan et al., 2021). The teacher's role shifts from primary knowledge transmitter to facilitator and AI orchestrator, demanding ongoing professional development supported by multi-stakeholder frameworks.

Methods

Research Methodology

This study employed a qualitative approach, specifically a holistic single-case study design (Yin, 2017), to examine the *Bakti Pendidikan Saka 2023* programme in depth and context. The case study design was appropriate because, despite involving multiple informant categories representing various stakeholder elements, the inquiry was bounded within a single programme context, enabling an in-depth reconstruction of the Pentahelix collaboration model from observed stakeholder dynamics.

Population and Sample

Five participant categories were involved using purposive sampling to ensure maximum variation across school types, districts, and stakeholder roles: (1) PT SIPL management (n = 3, including board directors and programme managers responsible for CSR strategy and implementation); (2) Gresik Regency Government representatives from the Education Office and the Ministry of Religion Office, the two agencies with direct oversight of secondary school governance in the district; (3) academic facilitators from the State University of Malang (UM) and the Open University, selected for their expertise in educational technology and professional development design; (4) 28 secondary school teachers from 14 schools spanning SMA, SMK,

and MA levels across Manyar and Ujungpangkah districts, with two teachers per school to ensure within-school comparison; and (5) local mass media representatives from print and digital outlets involved in CSR programme coverage. This multi-category sampling strategy ensured that the full Pentahelix collaboration structure was captured empirically, with each actor category represented in the data.

Data Collection Tools and Validity

Data were gathered through four instruments: (a) in-depth interviews with teachers and stakeholders to elicit contextual insights; (b) participant observation of teaching practices and AI tool deployment; (c) documentary study of internal programme documents including training manuals, implementation reports, and evaluation materials produced by PT SIPL—authentic records triangulated against other sources to mitigate bias; and (d) Focus Group Discussions (FGDs) with teacher cohorts to surface collective perspectives. Credibility was ensured through data triangulation and member checks; dependability via an audit trail; confirmability through consistent analytical procedures applied across all participant categories; and transferability through thick contextual description of the research site, programme design, and participant demographics. The documentary evidence base relied on internal programme records produced by PT SIPL, a limitation mitigated through triangulation with independent interview and observational data from teachers, government representatives, and media actors not affiliated with the implementing organisation.

Data Analysis Procedure

Thematic analysis followed a modified inductive model (Bogdan & Biklen, 2007) involving iterative cycles of organising, coding, and interpreting data. The analytical process proceeded in three sequential phases. In the first phase, raw data from interviews, FGDs, and observations were transcribed, organised by participant category, and subjected to open coding to identify recurring concepts and patterns. In the second phase, codes were grouped into thematic categories corresponding to each research objective: AI utilisation profiles (Objective 1), barrier types (Objective 2), actor roles (Objective 3), and model structures (Objective 4). In the third phase, themes were interpreted in relation to the conceptual framework and existing literature. To ensure consistency and reduce subjectivity in coding, all thematic categories were discussed among the research team and cross-checked against documentary evidence from programme records. Competing interpretations were resolved through peer debriefing sessions, which formed part of the dependability audit trail. The data saturation principle guided the decision to conclude data collection: when no new codes or themes emerged from the fifteenth interview onward, the team confirmed that sufficient informational depth had been reached. Member checking was conducted with six teacher participants and two government representatives, who reviewed the initial thematic summaries and confirmed that the interpretations accurately reflected their experiences. This procedure strengthened both the credibility and confirmability of the findings by ensuring that analytical interpretations did not diverge from participants' lived realities. All data were anonymised at the coding stage, with schools identified by abbreviation codes (e.g., SMA AM, SMK Y) and individual teachers by initials only, consistent with ethical standards for qualitative research involving vulnerable participants. For Objective 1, AI understanding levels were determined using a three-tier rubric (Very Low / Low / Moderate) applied during thematic coding of interview transcripts, validated through triangulation with teacher portfolios (lesson plans, AI-integrated materials, AI tool screenshots). For Objective 2, barrier categories were derived inductively from interview and FGD data. For Objectives 3 and

4, stakeholder roles and the Pentahelix model were reconstructed through cross-stakeholder thematic synthesis and documentary analysis, ensuring the framework reflects observed rather than assumed collaboration patterns.

Results

SETs' Current AI Utilisation and Understanding

Interviews with 28 teachers across 14 schools showed 17 (60%) had used AI tools in learning contexts, while 11 (40%) had not. Analysis of responses revealed persistent misconceptions: many teachers conflated non-AI digital tools—PowerPoint Maker (GammaAI, etc.), Google Forms, Zoom, Google Books—with genuine AI applications such as ChatGPT and Assemblr Edu. AI understanding levels, determined through rubric-guided thematic coding triangulated with portfolio artefacts, were classified as: Moderate (60%, n = 17), Low (30%, *n* = 8), and Very Low (10%, *n* = 3). The rubric assessed clarity of AI concept explanation, accuracy of tool identification, and portfolio evidence of pedagogical application. Full participant-level data are presented in Table 1.

Table 1: Secondary Education Teachers' AI Utilisation and Understanding Profiles

No.	School	Code	Used AI	Misconception (AI/Non-AI Apps)	AI Understanding (Very Low/Low/Moderate)	Training	Need AI Skills
1	SMA AM	AS	Never	–	Low	Yes	Yes
		FDF	Used	Canva	Moderate	Yes	Yes
2	SMA M9	IN	Used	Canva, PowerPoint Maker (GammaAI, etc.), Google Forms	Moderate	Yes	Yes
		FN	Never	–	Very Low	No	Yes
3	SMA AFS	ZS	Never	–	Low	Yes	Yes
		AE	Used	ChatGPT	Moderate	Yes	Yes
4	SMA Y	M	Never	–	Very Low	No	Yes
		FR	Used	Teaching Modules, PowerPoint Maker (GammaAI, etc.)	Low	Yes	Yes
5	MA AM	Q	Never	–	Very Low	No	No
		AR	Used	Google Classroom	Moderate	Yes	Yes
6	MA AF	R	Used	–	Low	Yes	Yes
		AS	Used	Google Forms	Moderate	Yes	Yes
7	MA IS	FZ	Used	Teaching Modules	Low	Yes	Yes
		AR	Used	Chatbot	Moderate	Yes	Yes
8	MA M4	HM	Never	–	Low	No	Yes
		KW	Used	Canva	Moderate	Yes	Yes
9	MA Y	AY	Used	Zoom Meeting	Low	No	Yes
		MS	Used	PowerPoint Maker (GammaAI, etc.)	Moderate	Yes	Yes
10	MA AI	MS	Never	–	Low	No	Yes
		RU	Used	ChatGPT	Moderate	Yes	Yes

No.	School	Code	Used AI	Misconception (AI/Non-AI Apps)	AI Understanding (Very Low/Low/Moderate)	Training	Need AI Skills
11	MA AM	RZ	Never	–	Low	No	Yes
		HS	Used	Canva	Moderate	Yes	Yes
12	SMK RH	NH	Used	Google Books	Moderate	Yes	Yes
		QA	Used	ChatGPT, Canva	Moderate	Yes	Yes
13	SMK MI	MU	Never	–	Low	No	Yes
		IS	Never	–	Very Low	No	Yes
14	SMK Y	SA	Used	Assemblr Edu	Moderate	Yes	Yes
		MA	Used	Google Forms	Moderate	Yes	Yes

Note: SMA = Senior High School; MA = Madrasah Aliyah (Islamic Senior High); SMK = Vocational High School. Training = Participation in PT SIPL-organised AI professional development. Very Low/Low/Moderate = levels from rubric-guided thematic coding validated by portfolio artefacts.

Regarding training participation, 70% (n = 20) attended PT SIPL's AI training programmes covering AI use, interactive e-module development, Quizizz, standalone LMS creation, flipbook development, and Assemblr Edu, while 30% (n = 8) did not, indicating uneven access. Concerning the need for AI skills, 90% (n = 25) reported requiring AI for work efficiency, teaching effectiveness, curriculum demands, and administrative tasks; 10% (n = 3) perceived no need, linked to very low conceptual understanding. Portfolio triangulation confirmed a significant gap between awareness and actual pedagogical application across all understanding levels.

Barriers to AI Integration

Five interrelated barrier categories were identified inductively from interview and FGD data. Figure 1 presents the gap between current conditions and ideal requirements for each barrier.

Barrier Category	Ideal Condition	Current Reality (Gresik)
Knowledge & Skills Foundational AI literacy and pedagogical skills	Solid AI concept knowledge; hands-on training tailored to classroom application	60% moderate; 40% low/very low; misconceptions: PowerPoint, Google Forms labelled as AI
Access & Infrastructure Devices, internet, AI-ready platforms	Reliable internet; AI-enabled devices equitably distributed to all schools	Inconsistent connectivity; device shortage in rural Manyar & Ujungpangkah
Resources & Support Funding, tools, institutional backing	Adequate funding; professional development for all; institutional AI culture	70% attended training; 30% excluded due to budget constraints
Uncertainty of Benefits Evidence of AI value in learning outcomes	Evidence-based showcases; success stories readily available to teachers	Only 10% confident in AI-driven adaptive teaching; widespread skepticism persists
Curriculum Alignment AI-integrated curriculum standards and resources	AI-specific standards, materials, and evaluation tools embedded in curriculum	No AI-specific program standards; especially acute in vocational schools (SMK)

Figure 1: Matrix of secondary education teachers' barriers to AI utilisation.
(Source: Own construction from research findings.)

Knowledge and skills limitations were the most pervasive barrier across all school types and districts. Forty percent of SETs could not distinguish AI from conventional digital tools, and even Moderate-classified teachers frequently limited explanations to tool naming rather than pedagogical rationale. For instance, several teachers cited Canva as an AI tool because it features an AI-powered design suggestion function, without recognising that Canva is a general design platform with an AI component. This category confusion indicates exposure to AI through product interfaces without conceptual grounding in how AI functions. Infrastructure challenges were particularly acute in rural Ujungpangkah schools, where inconsistent electricity and limited device availability restricted hands-on training to one or two tools per session, and where unreliable internet connectivity made cloud-based AI platforms such as ChatGPT effectively inaccessible during school hours. SMK vocational school teachers most consistently reported curriculum absence as a barrier: nationally mandated Vocational Competency Standards contained no AI-specific performance indicators, leaving teachers without guidance for tool selection, lesson design, or AI-aligned student assessment. These five barriers are deeply interconnected: infrastructure gaps constrain training access; reduced participation sustains misconceptions; misconceptions fuel benefit uncertainty; and curriculum absence removes the scaffolding needed to convert individual competence gains into sustained classroom practice. Addressing any single barrier in isolation—as prior one-off training interventions have done—produces only marginal, unsustainable improvement, reinforcing the case for a multi-actor, systems-level Pentahelix approach.

Roles of Pentahelix Actors

Each Pentahelix actor contributed distinct but complementary functions, operating not as parallel independent actors but as a synergistic system in which each actor's contribution amplified the impact of the others. Figure 2 illustrates the role structure and relationship patterns among the five actors. The model reveals both vertical alignment—government policy enabling industry investment, which in turn enables academic programme design—and horizontal integration, whereby community and media actors simultaneously build the social and public legitimacy required for institutional changes to take root at the classroom level. This dual alignment distinguishes the Pentahelix from simpler partnership models and accounts for its effectiveness in contexts where individual actor interventions have historically struggled to produce lasting outcomes.

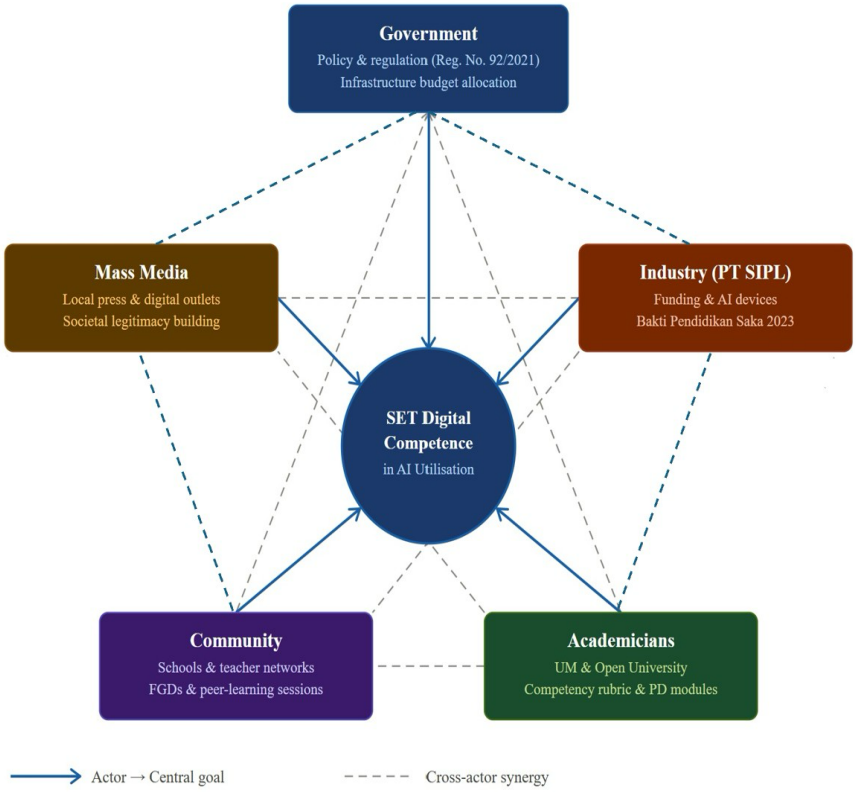

Figure 2: Role structure and relationship patterns of key actors in Pentahelix collaboration for fostering digital competence of SETs in AI utilisation.
(Source: Own construction from research findings.)

The Government (Gresik Regency) served as regulatory and resource anchor, enacting CSER policy under Regent Regulation No. 92/2021, legitimising PT SIPL's initiative as policy-aligned rather than purely philanthropic, and consulting with academicians to align training with district educational priorities. Industry (PT SIPL) functioned as the primary operational enabler: procuring AI-enabled devices, funding training infrastructure, and managing the programme through its corporate social responsibility framework. Academicians (UM and Open University) served as knowledge architects and quality assurance agents—designing professional development modules, constructing the three-tier competency rubric, and conducting portfolio-based validation. Community (teacher cohorts and school networks) provided peer-learning

infrastructure through FGDs and workshops, building a local community of practice where AI-integrated lesson plans were exchanged and practical classroom strategies co-developed. Mass Media (local press and digital outlets) built societal legitimacy for AI adoption, normalising AI use in schools, reducing parental and community scepticism, and motivating teacher risk-taking through public recognition—a contribution frequently overlooked in AI integration literature (Khan et al., 2021; Ohara, 2023).

The Reconstructed Pentahelix Model

Drawing on findings from Objectives 1 through 3, Figure 3 presents the reconstructed Pentahelix collaboration model for building SET digital competence in AI utilisation, mapping each actor's barriers addressed, actions taken, and achievement indicators.

Pentahelix Model: Building SET Digital Competence in AI Utilisation

Actor	Barrier Addressed	Actions Taken	Achievement Indicators
Government (Gresik Regency) Reg. No. 92/2021 CSER policy	Infrastructure gaps; absent curriculum standards	Budget for internet/devices; AI curriculum guidelines; CSER compliance mandate; consultations with academicians	Policy instruments enacted; equitable resource distribution; AI embedded in official curriculum frameworks
Industry (PT SIPL) *Bakti Pendidikan Saka 2023*	Resource scarcity; knowledge gaps; lack of technical support	Procure AI-enabled devices; fund structured training (ChatGPT, Assemblr Edu); CDP programme management	70% teacher training participation; measurable tool proficiency; demonstrated programme delivery within 1 cycle
Academicians UM & Open Univ. Expert facilitators PD designers	Weak AI foundations; curriculum misalignment; no assessment tools	Design PD modules; build 3-tier competency rubric; evidence-based curriculum; portfolio triangulation	Validated rubric published; portfolio artefact evidence; transferable assessment tool for future programmes
Community Schools, teacher networks, FGDs Peer learning	Benefit uncertainty; limited peer learning channels; low confidence	Organise FGDs & workshops; share AI lesson plans; peer success stories; community of practice	Increased teacher confidence; reduced AI misconceptions; local best-practice repository established
Mass Media Local press Digital outlets Advocacy	Limited public awareness; societal scepticism about AI in schools	Cover AI adoption stories; advocate for digital education; normalise AI use in public discourse	Positive public sentiment; community support for AI learning; teacher motivation through social recognition

Figure 3: Pentahelix model for building secondary education teachers' digital competence in AI utilisation. (Source: Own construction from research findings.)

Discussion and Implications

The four findings of this study converge on a single overarching interpretation: AI integration in under-resourced secondary education cannot be addressed through any single-actor intervention, however well-resourced. The observation that 60% of teachers reached only a moderate AI understanding—despite varying prior digital training—signals a deeper conceptual gap rather

than a skills deficit. This pattern is consistent with Aravantinos et al. (2026), who synthesised 43 empirical studies and concluded that technical training alone is insufficient for AI integration; effective adoption requires combined alignment of pedagogical knowledge, attitudes, organisational support, and continuous professional development. The teacher misconceptions documented in Gresik—conflating PowerPoint Maker (GammaAI, etc.), Google Forms, and Canva with genuine AI applications—are therefore symptomatic of an international pattern. Comparable conceptual confusions have been reported among Indonesian primary teachers (Batubara, 2026), in surveys of Indonesian K-12 teachers across 25 provinces (Harsanti et al., 2025), and in qualitative studies of rural EFL educators (Dinata et al., 2025). What this study contributes is a structural explanation: misconceptions persist because tool-centric training, divorced from conceptual scaffolding and assessment-anchored evidence, leaves teachers unable to distinguish AI from non-AI digital tools. The Gresik programme addressed this gap by combining tool exposure with academician-designed conceptual rubrics—an integration largely absent from CSR training models in the international evidence base.

A second contribution of this study lies in advancing Pentahelix theory beyond its conventional parallel-actor formulation. Prior applications in Indonesian education (Hoerniasih et al., 2022; Yunas et al., 2023) and adjacent governance domains (Sulaeman et al., 2021) describe Pentahelix actors as occupying discrete functional silos—government provides regulation, industry funding, academia knowledge, community participation, media publicity. The Gresik case challenges this additive conception. Industry resourcing without academic scaffolding produced training participation without measurable understanding gains; teachers who attended PT SIPL training but did not engage in portfolio-based application showed competence levels barely distinguishable from untrained peers. Conversely, academic rigour without industry resourcing would have remained confined to scholarly publication, never reaching the 28 teachers across 14 schools at scale. This empirical finding aligns with Lucas et al. (2024), whose European study established that AI-specific knowledge—not generic digital competence—predicts teacher trust and adoption, and with Sanusi et al. (2023), who emphasised that effective AI competency development requires contextually responsive professional learning pathways. The actor-role synergy documented here is therefore structural rather than additive: removing any single actor qualitatively alters programme effectiveness, newly specifying for AI-in-education contexts what earlier theorists proposed only at the level of governance abstraction.

A third contribution—frequently underexplored in the AI-in-education literature—concerns the legitimating function of mass media in collectivist educational contexts. While most reviews of AI integration focus predominantly on classroom and institutional factors (Chiu et al., 2023; Zawacki-Richter et al., 2019), the Gresik findings demonstrate that media advocacy operated as a primary vehicle of social legitimation: positioning participating teachers as innovators, normalising AI-enhanced teaching, and reducing parental scepticism that might otherwise constrain classroom experimentation. This sociocultural mechanism extends the arguments of Khan et al. (2021), Moldalieva et al. (2025), and Zhang et al. (2021) on public engagement in technology integration, and aligns with recent EdTech Hub findings (Jayasinghe et al., 2025) that EdTech sustainability across Southeast Asia depends on aligned public-sector legitimacy and community trust. In collectivist Indonesian contexts, where community perception substantively shapes school-level practices and teacher professional identity, media participation is not auxiliary publicity but a core legitimating mechanism that enables the other four actors to function. This study also extends the empirical base by documenting evidence from secondary education in a middle-income, CSR-driven context, including MA teachers

navigating dual Ministry governance—a regulatory complexity not yet theorised in the existing literature.

For 'Learning for Development' scholarship and practice, the findings reframe AI integration as a developmental systems challenge rather than a technological one. The persistent infrastructure deficits documented here—inconsistent connectivity in rural areas, device shortages in MA and SMK schools, and absent AI curriculum standards—mirror national-level barriers identified by Herviana (2025) and Haetami (2025), and by Hanifah et al. (2025) across developing-country basic education systems. Addressing these barriers requires the simultaneous activation of policy legitimacy, material resources, human capital, social capital, and public legitimacy—each corresponding to one Pentahelix actor. For technology-enabled and blended learning specifically, the Gresik case demonstrates that AI cannot be effectively blended into instructional practice without first establishing the socio-institutional preconditions for adoption. The UNESCO AI Competency Framework for Teachers (Miao & Cukurova, 2024) similarly positions institutional support, professional development, and ethical governance as preconditions for sustainable integration. The Pentahelix model thus operationalises a blended-learning readiness infrastructure replicable across comparable secondary education contexts in Indonesia and Southeast Asia.

A final contribution concerns the three-tier competency rubric validated through portfolio triangulation. The persistent gap between teacher self-reported competence and demonstrated classroom practice—a recurring methodological problem (Lucas et al., 2024; Sperling et al., 2024)—cannot be closed by self-assessment alone. By anchoring competence judgements in observable artefacts (lesson plans, AI-integrated materials, AI tool screenshots), the Gresik rubric operationalises a more robust and less biased measure that other AI professional development programmes can adapt. For policymakers across Indonesia and Southeast Asia, the policy implication is direct: scaling AI integration in secondary education requires embedding multi-stakeholder collaboration structures within existing CSR governance instruments such as Indonesia's Regent Regulation No. 92/2021, aligning competency rubrics with national curriculum standards, and investing in community peer-learning networks that sustain competence gains beyond single intervention cycles. Indonesia's recently launched National AI Roadmap (Komdigi, 2025), which recognises multi-stakeholder coordination as foundational to AI talent development, provides a national policy infrastructure within which district-level Pentahelix programmes can be situated and scaled.

Limitations and Directions for Further Research

Several limitations frame the interpretation of these findings. The single case-study design restricts generalisation beyond the conditions of Gresik Regency. The documentary evidence relied predominantly on internal PT SIPL records, mitigated through independent triangulation but not externally audited. Competence was assessed at a single point, leaving the sustainability of gains unconfirmed. The three-tier rubric, although validated through portfolio triangulation, requires inter-rater reliability testing before standardised use. Future research should pursue multi-site comparisons to test transferability; longitudinal designs spanning two or more academic years to assess sustainability; and mixed-methods studies incorporating pre-post assessments of teacher competence and student learning outcomes to establish causal links—an evidentiary gap noted in recent reviews (Chiu et al., 2023; Zheng et al., 2023). Examination of gender differentials, school leadership mediation (Harsanti et al., 2025), and comparative studies

of national AI policy frameworks in Singapore, Malaysia, and Thailand would advance this inquiry.

Conclusion

This study demonstrates that Pentahelix collaboration—structured engagement among government, industry, academicians, community, and media—constitutes an effective, contextually grounded framework for building secondary school teachers' AI-enabled digital competence in under-resourced settings. The reconstructed Pentahelix model offers a replicable, policy-aligned blueprint for policymakers, CSR practitioners, academic institutions, and educator communities across Indonesia and the Global South seeking to scale sustainable, equitable AI integration in secondary education.

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