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Fragmented ecosystem, emergent roles: The limits of the penta helix model for sustainable digital resilience

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Abstract The paradox of urban digital transformation—immense opportunity shadowed by significant risks such as digital divides, misinformation, and cybersecurity threats—requires a unified, multi-sector collaborative effort. The Penta Helix model, which theoretically convenes academia, business, government, community, and media, is a framework increasingly adopted in developing nations to organize and govern such efforts. However, its practical application and actual effectiveness in fostering sustainable digital literacy resilience, a crucial component of urban defense against digital risks, remain an underresearched topic. This study addresses this critical gap through an in-depth qualitative case study of Surakarta, Indonesia, a city actively pursuing smart city status. Drawing on semistructured interviews with seven key Penta Helix actors representing each of the five sectors, alongside a thematic analysis of public policy documents and municipal reports, this paper investigates the collaborative dynamics shaping the city's digital literacy initiatives. The findings uncover a critical 'evaluation gap' across the ecosystem, defined by a profound lack of shared, outcome-based metrics and integrated monitoring processes, which prevents any collective understanding of programmatic impact. Consequently, the ecosystem operates not as a coordinated coalition but as a fragmented system with significant collaborative challenges. Actors have settled into emergent, specialized roles—such as academia focusing on foundational training and community groups on grassroots dissemination—which, while complementary, exist in programmatic silos with minimal inter-sectoral communication. This fragmentation, characterized by redundant efforts and a lack of integrated strategy, hinders the overall impact. Furthermore, this siloed approach means any alignment with broader Sustainable Development Goals (SDGs), such as SDG 4 (Quality Education) and SDG 11 (Sustainable Cities), is largely implicit and opportunistic rather than strategic. This research provides a practical, grounded critique of the Penta Helix model in action, concluding that creating a truly resilient digital community is impossible without an integrated, evidence-based strategy, one that moves beyond siloed actions toward a system-wide, data-driven governance model.

Keywords: collaborative governance, digital literacy, smart city, program evaluation, policy fragmentation

1. Introduction

Cities worldwide are racing to digitize, but this transformation comes with a steep price: the challenge of building a resilient citizenry in an age of rampant misinformation. The proliferation of digital technologies has created a complex information ecosystem where disinformation and hoaxes can spread rapidly, threatening social cohesion and democratic processes (Guess, 2020). This issue is particularly acute in Indonesia, a nation with one of the highest numbers of active social media users globally, where the Ministry of Communication and Information Technology has identified and taken down thousands of hoax and negative websites annually (INP, 2024, 2025a). This problem was compounded in 2025 when Indonesia was hit by a surge of online gambling issues, with people using social assistance money to deposit online gambling (INP, 2025b; Rusmana, 2025). This digital paradox—of connection and corrosion—places immense pressure on local governments to move beyond simply providing technological infrastructure and toward fostering digitally resilient citizenry.

In this context, the city of Surakarta represents a compelling microcosm of Indonesia's digital challenge. As a cultural and economic hub in Central Java, it is a key participant in the national 'Smart City' movement—an initiative focused on integrating digital technology into urban management (Surakarta, 2023). This focus is amplified by the city's unique political context, which has also made it a site of prominent national investment (Susanti & Khu, 2025). In this high-profile context, the digital paradox becomes most clear: the city must champion technological progress while simultaneously building its citizens' resilience against the digital threats that follow.

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To navigate this complex landscape, multistakeholder collaboration is essential. Policymakers in Indonesia widely adopt the Penta Helix model as a go-to strategy for tackling complex societal issues, from tourism development (Chamidah, 2020; Cita, 2025; Hardianto, 2019; Lagarense, 2018; Noviana, 2025; Rahatmawati, 2021; Rahayu, 2024; Soemaryani, 2016; Subair, 2025; Widhiasthini, 2025) and industry (Muhyi et al., 2017) to deradicalization (Subagyo, 2021). However, a significant gap exists in the academic literature regarding the intersection of the Penta Helix model and digital literacy. Prominent research in the field of digital literacy has focused mostly on professional (Cetindamar, 2024a, 2024b; Diseiye, 2024) and educational (Falloon, 2020; Getenet, 2024; Meng, 2025; Nguyen, 2024; Prior, 2016; Spante, 2018; Zhang, 2024) aspects.

Thus, while the Penta Helix model has largely focused on economic innovation and digital literacy has evolved into a critical "survival skill" (Eshet, 2004), there is a clear lack of empirical research investigating how the Penta Helix framework is applied in practice to build city-wide digital literacy resilience. The literature extensively discusses the theoretical advantages and practical challenges of the Penta Helix model and thoroughly explores the multifaceted nature of digital literacy, but these two conversations rarely intersect. It remains unclear whether the model's theoretical promise of synergy translates into an effective, coordinated strategy for creating a digitally informed citizenry. This study seeks to bridge this pressing gap by providing an empirical case study that explores whether multistakeholder synergy can address the profound challenge of community-wide digital resilience.

To achieve this, the research explores the specific roles and contributions of each helix, the primary challenges and successes in their collaboration, and how their collective initiatives contribute to building digital literacy against misinformation. The analysis also considers the extent to which these efforts align with key Sustainable Development Goals (SDGs), such as those related to quality education (SDG 4) and decent work (SDG 8). This paper presents the findings through four interconnected themes that emerged from the data: (1) a systemic 'evaluation gap' in measuring success; (2) the reality of a 'fragmented ecosystem' with only pockets of collaboration; (3) the 'emergent specialization' of each helix into distinct, unofficial roles; and (4) the role of 'community vulnerability' as the primary driver for the entire ecosystem.

Before examining the specific case of Surakarta, however, it is necessary to first establish the theoretical foundations of this study. The following section reviews the key academic conversations surrounding collaborative governance, tracing the evolution of the Penta Helix model from its origins. It will then explore the scholarly consensus on digital literacy, defining it not merely as a technical skill but also as a critical component of modern citizenship. This theoretical groundwork provides the analytical lens required to interpret the findings from Surakarta.

2. Literature Review

2.1. The Evolution of Collaborative Governance: From Triple to Penta Helix

The concept of collaborative governance has evolved over the past few decades, particularly as an alternative to traditional, top-down policymaking (Ansell & Gash, 2008). This approach brings public and private stakeholders together for consensus-oriented decision-making, driven by the need to address complex, interdependent problems that no single actor can solve alone. The foundational framework for this in innovation studies is the Triple Helix model, which focuses on the dynamic interactions among universities, industry, and the government (Etzkowitz & Leydesdorff, 2000). This nonlinear model suggests that innovation occurs at the interfaces of these three spheres, with universities, for example, taking on a "third mission" of supporting economic development beyond just teaching and research.

Recognizing the limitations of a purely economic and administrative focus, this concept was expanded to the Quadruple Helix, which integrated a fourth actor: the "media-based and culture-based public" (Carayannis & Campbell, 2010). This highlights the important role of civil society, culture, and values in shaping innovation. The model further evolved into the Quintuple Helix, which added the "natural environment" as a fifth helix to embed the principles of sustainable development and social ecology into the framework (Carayannis & Campbell, 2010).

In practical applications, particularly within the Indonesian context, the term Penta Helix is often used. This model originates from early city-focused innovation frameworks (PricewaterhouseCoopers, 2005; Sturesson et al., 2009) and initially defined the five actors as government, university, private sector, nonprofit, and citizen. Because of this focus on urban development, the approach became popular within the context of city-based Indonesian research (Muhyi et al., 2017). While sometimes used interchangeably with the Quintuple Helix (Sumarto et al., 2020), the Indonesian application frequently makes a subtle but significant shift by explicitly naming "media" the fifth distinct helix, alongside the government, academia, business, and community (Chamidah, 2020; Subagyo, 2021). This highlights the media's critical functional role as an "information power" essential for promotion, public opinion shaping, and campaigning.

However, the promise of these expanded helical models is tempered by significant practical challenges. The literature on collaborative governance points to numerous difficulties, including "gaps between interests, expectations, and reality," conflicts of interest, and budget limitations (Chamidah, 2020). Effective collaboration requires mutual trust and commitment, which are time-consuming to build and can be undermined by a prehistory of antagonism, leading to what Ansell and Gash's (2008) term "collaborative inertia," where a flurry of activity fails to produce meaningful outcomes.

2.2 Digital literacy: From technical skill to resilient practice

The concept of digital literacy, first coined by Paul Gilster (Pool, 1997), has moved far beyond mere technical proficiency. It is now understood as a complex set of competencies required to navigate the digital world effectively and critically. To clarify this, Eshet (2004) proposed a holistic framework of interlocking skills. He identified *information literacy*, the ability to evaluate the validity of data, and *reproduction literacy*, the skill of ethically creating new content from existing material. Crucially, he also included *socioemotional literacy*—the capacity to understand cyberspace's social dynamics to avoid "traps." Together, this framework reframes digital literacy not as a technical task but as a set of "survival skills" for the modern era.

More recent scholarship has pushed toward the even broader concept of digital competence, which encompasses not only skills but also the knowledge, attitudes, and dispositions necessary to function "ethically, safely, and productively" in a digital environment (Falloon, 2020). Embedded within this is the concept of digital resilience—the capacity of individuals and communities to adapt effectively, withstand, and thrive amidst digital challenges such as misinformation and online scams. Research shows that while digital media literacy interventions can be effective at distinguishing between true news and false news, these effects can be modest and require reinforcement, highlighting the deep-seated nature of the challenge (Guess, 2020).

Digital literacy holds a unique position within global development frameworks such as the Sustainable Development Goals (SDGs) (UN, 2015). While SDG 4 aims to ensure inclusive and equitable quality education, its targets focus explicitly on "literacy and numeracy" (SDG Target 4.6). Digital literacy is not explicitly mentioned, making it an implicit requirement for modern education rather than an explicit global target. This absence of an explicit global mandate means that responsibility falls directly to local and national actors, who must themselves interpret and strategically integrate this crucial 21st-century skill into their development agendas.

3. Methods

3.1. Research Design and Theoretical Framework

This study employs a qualitative case study approach to construct an in-depth, contextualized understanding of the Penta Helix collaboration in Surakarta, Indonesia. This approach is particularly well suited for answering "how" and "why" questions about the dynamics between multiple actors in a complex, real-world setting. The analysis is framed by the Penta Helix model of collaborative innovation, which posits that sustainable development requires synergistic collaboration among five key societal actors: the government, academia, business, community, and media. This study uses the Penta Helix model not as a rigid prescription but as an analytical lens to map the roles, relationships, and collaborative friction points within Surakarta's digital literacy ecosystem. The research design is exploratory in nature, aiming to generate insights from the specific context of Surakarta.

3.2. Data Sources and Collection

To construct a rich and multifaceted view of the case, this study draws upon two primary forms of data collected between June and July 2024. First, semi-structured in-depth interviews were conducted with seven key informants selected through purposive sampling, with criteria requiring participants to hold a leadership or strategic role within an organization central to Surakarta's digital literacy initiatives. The participants included officials from government and public relations associations, academic representatives (senior lecturers and doctoral students), senior prominent local media editors, and community leaders, who represented each of the five helices. To ensure participant comfort and candor, detailed minutes were taken during the interviews in lieu of audio recordings. Second, to supplement and triangulate the interview data, a comprehensive corpus of documents was also gathered. This included a detailed analytical report on local digital literacy programs, official government websites and news articles from local media outlets, and publications from civil society organizations.

3.3. Data analysis

This study employed qualitative thematic analysis to interpret the data (Ahmed et al., 2025), following the six-phase framework developed by Braun and Clarke (2006, 2022). This process involved:

Familiarization**:** Repeatedly reading the interview minutes and collecting documents to gain an intimate understanding of the data.

Initial Coding**:** Systematically identifying and labeling interesting features of the data relevant to the research questions.

Theme Generation**:** Collating the codes into potential themes and gathering all relevant data extracts under each theme.

Theme Review**:** Reviewing and refining the potential themes to ensure that they are coherent and distinct.

Theme Definition**:** Finalizing the specific meaning and scope of each theme and giving them analytical names.

Report Production**:** We weave the analysis of the themes into a cohesive narrative, supported by direct evidence from the data.

4. Results and Discussion

The thematic analysis of interview minutes and public documents reveals a complex and dynamic digital literacy ecosystem in Surakarta. To answer the research questions, the findings are organized into four key themes, with Table 1 providing a summary of the emergent roles and collaborative dynamics of each helix.

Table 1 Roles and dynamics of Helix in Surakarta's Digital Literacy Ecosystem.

Helix	Emergent Role in Digital Literacy	Key Initiative/Action	Primary Challenge/Friction Point
Government	Infrastructure & Foundational Skills Provider	Solo Destination App; City Library Training	Departmental silos (Dispora); lack of outcome-based metrics.
Academia	Advanced Training & Ethics Bridge	Hosting national DTS programs; embedding ethics in curriculum.	Lack of direct, visible collaboration with other local actors.
Business	Tactical Implementation Partner	Gradasi partnership to train MSMEs on sales.	Role appears limited to partnerships; no independent public initiatives found.
Community	Critical Citizenship & Resilience Builder	LKLK workshops on disinformation; PKK identifying hoax vulnerability.	Faces the direct impact of low digital literacy and misinformation.
Media	Public Verifier & Educator	Fact-checking teams; 'prebunking' initiatives.	Tension with government's desire for a 'single narrative.'

As the summary in Table 1 illustrates, the data reveal several overarching patterns regarding the roles and interactions of Penta Helix actors. The following sections present a detailed analysis of four key themes that emerged from the data, weaving together the evidence, interpretation, and connection to the broader scholarly conversation.

4.1. Theme 1: The evaluation gap: A crisis of measurement

A central finding of this study is the existence of a significant 'evaluation gap' across Surakarta's digital literacy landscape. As visualized in Figure 1, the metrics that are publicly reported represent only the visible 'tip of the iceberg,' whereas the more substantive measures of impact remain submerged and unassessed. The data from both interviews and documents show that success is predominantly defined by outputs and promotional achievements rather than by demonstrable impacts on skills or resilience. For example, the Solo Destination mobile application, a cornerstone of the government's digital tourism strategy, is frequently lauded for receiving a MURI (Indonesian World Records Museum) award. This award, as noted in the analytical report, recognizes the novelty of the innovation but serves as a metric of public relations success, not of impact. The available data do not provide insights into user adoption rates, the economic benefits for local businesses, or whether the app has improved the digital skills of its users.

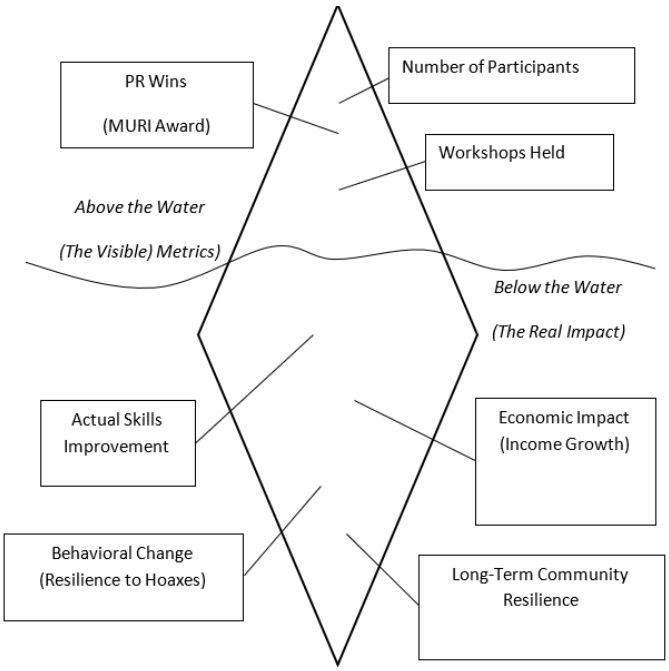

Figure 1 Iceberg diagram of evaluation metrics.

This reliance on vanity metrics over impact metrics develops as a recurring pattern, with the analytical report noting that success is often conveyed through "output-based data" such as participant numbers rather than meaningful outcomes. Amplifying this finding, the informants in the interviews were often general when asked about success metrics and presented no concrete data on skills improvement or behavioral change. This suggests that while individual actors are actively engaged in delivering programs, the ecosystem as a whole is operating without the feedback loops necessary for evidence-based policymaking. Without knowing what works, resources may be allocated inefficiently, and programs may fail to address the most critical needs of the community—a challenge directly identified by the PKK representative, who noted that "digital literacy is still lacking." This is a direct consequence of operating without a central coordinating body; in the absence of a mandated, unified framework for evaluation, each actor defaults to its own superficial metrics, causing a holistic, city-wide picture of digital resilience to never emerge.

This finding connects directly to the core debates in digital literacy theory. The focus on visible, output-based metrics risks reducing digital literacy to a set of easily measurable technical skills, a narrow approach that scholars have cautioned against (Falloon, 2020). It fails to assess whether citizens are developing the deeper, more complex competencies—such as the "information literacy" and "socioemotional literacy" that Eshet (2004) deemed "survival skills"—that are essential for true digital resilience. The implication of this evaluation gap, as illustrated by the iceberg diagram, is a potential future where the city has a false sense of security, celebrating the visible metrics of activity while the submerged, foundational challenges of community resilience remain unaddressed. This lack of a shared vision for what success looks like is a foundational challenge that can lead to the "collaborative inertia" described by Ansell and Gash (2008), where a flurry of activity does not translate into meaningful progress. This is not accidental oversight but rather a direct symptom of the fragmented and siloed nature of the collaborative ecosystem itself, which is the focus of the second theme.

4.2. Theme 2: A Fragmented Ecosystem with Collaboration Pockets

The data reveal that the Penta Helix in Surakarta does not operate as a unified, strategic coalition but rather as a 'fragmented ecosystem' characterized by programmatic silos and points of friction. The collaborative dynamics of this ecosystem, as illustrated in Figure 2, are defined by a mixture of undocumented partnerships, clear friction, and weak or nonexistent links. The analytical report explicitly notes this "programmatic fragmentation," a finding that is substantiated by several key pieces of evidence.

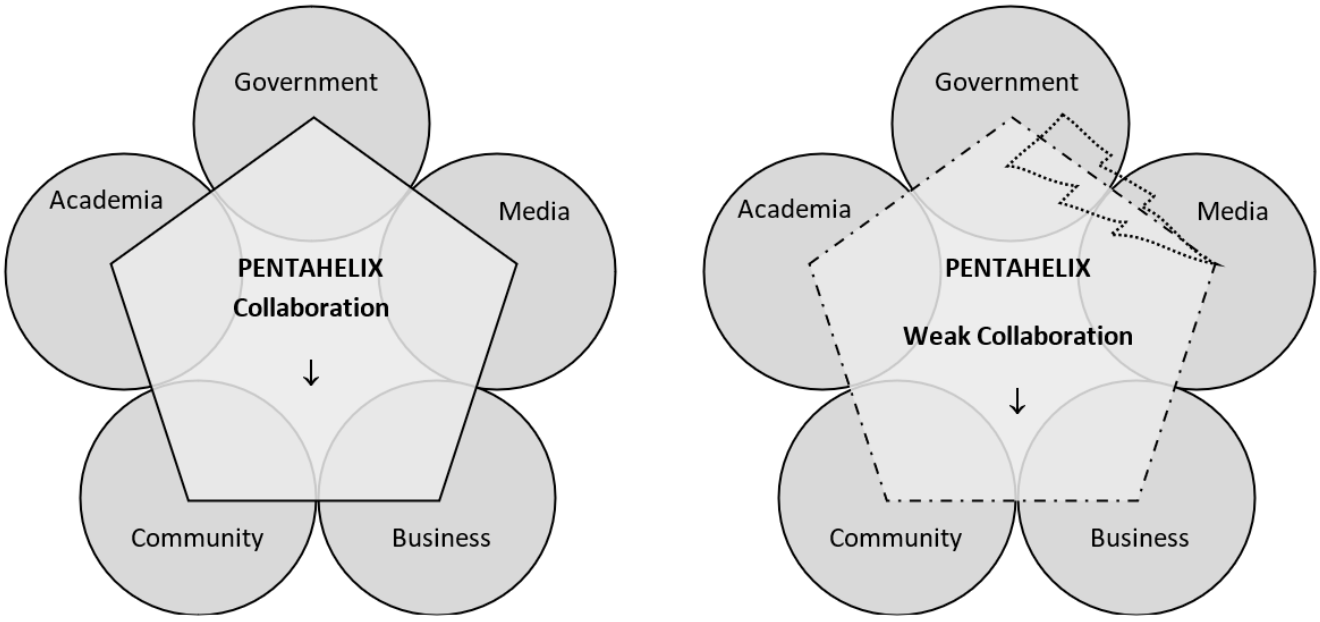

Figure 2 Collaboration matrix diagram (Ideal vs Real).

A clear example of this disunity is the siloed nature of government departments. The report illuminates that the Department of Youth and Sports (Dispora), the agency officially responsible for youth affairs, has a "limited, or at least undocumented, role" in digital literacy programming—a significant finding, as it suggests a lack of internal government coordination. This disconnect between departmental mandates and the cross-cutting nature of digital literacy is a policy issue. This oversight is also a textbook symptom of the missing central coordinating mechanism. A dedicated, overarching body would almost certainly mandate the youth department's involvement, but without it, imperative responsibilities are simply allowed to fall through the cracks of bureaucratic procedure.

This lack of synergy is further evidenced by the friction between the government and media helices. The media representative stated in their interviews that the relationship can be "challenging," particularly when the government "wanted to impose a single official narrative." This pointed to a fundamental conflict between the government's desire for message control and the media's role as a public watchdog, hindering the potential for synergistic collaboration. This is a classic challenge in collaborative governance, where autonomous actors with different core missions must find common ground (Thomson & Perry, 2006).

However, this fractured landscape is punctuated by successful "pockets of collaboration," which often arise to meet specific, practical needs. A key example is the partnership between Diskominfo SP (Government) and Gradasi (Business) to conduct a workshop for MSMEs aimed at "increasing turnover in the digital era". This demonstrates that when a clear, mutually beneficial, and often economic goal is present, cross-helix collaboration can occur effectively. These "pockets" serve as evidential case studies, but they do not represent a systemic, city-wide collaborative strategy.

This reality on the ground challenges the often idealized, synergistic depiction of helical models. It aligns with research highlighting the practical difficulties of collaboration, such as "gaps between interests, expectations, and reality" and conflicts of interest among stakeholders (Chamidah, 2020). The case of Surakarta demonstrates that even when all five helices are active, their interaction is not automatically harmonious and is subject to the real-world pressures of bureaucratic silos and competing institutional goals, leading to a system that is more reactive and disjointed than strategically integrated.

4.3. Theme 3: Emergent Specialization: The Unofficial Roles of the Helices

Paradoxically, the fragmented nature of the ecosystem has led to a dynamic of emergent specialization, where each helix has naturally gravitated toward a distinct and complementary role. This division of labor, presented in Table 2, is not the result of a coordinated, top-down strategy but rather an organic adaptation to the needs of the community and the core competencies of each actor.

Table 2 Functional Ecosystem of the Surakarta Penta Helix.

PENTAHELIX	Unofficial Roles
Government	Provides Infrastructure (Apps, etc.)
	Offers Foundational & Career Skills
Academia	Bridges to Advanced National Training
	Embeds Ethics in Curriculum
Business	Acts as Tactical Implementation Partner
	Focuses on Economic Goals (MSMEs)
Community	Builds Critical Citizenship Skills
	Responds to Ground-Level Needs
Media	Acts as Public Verifier (Fact-Checking)
	Serves as a Public Educator

A clear division of labor has emerged between the state and its citizens. The government helix, for its part, has assumed the role of an infrastructure and foundational skills provider, developing public goods such as the Solo Destination app and offering career-focused workshops on personal branding. This top-down approach, focused on tangible economic outcomes, stands in stark contrast to the work of the Community helix. Civil Society Organizations such as LKLK (*Lembaga Kajian Lintas Kultural*) have stepped in to arrange the agile, critical citizenship training that the state often cannot, organizing workshops on politically sensitive topics such as disinformation and "cyber armies." In this way, the community acts as the city's democratic conscience, addressing the rapidly evolving threats that government curricula are too slow to counter.

Academia also plays a dual role: as a bridge to advanced national training and as a source of ethical frameworks. On the one hand, it hosts programs such as the national Digital Talent Scholarship (DTS), providing specialized training in areas such as AI for marketing to the city. On the other hand, its curriculum actively shapes the next generation's digital values by instilling ethics and critical thinking, a point emphasized by the academic representative.

Acting as the public's verifier and educator, the Media helix embraces a role that, as its representative emphasized, extends far beyond mere reporting. This educational mission is fulfilled through rigorous, institutionalized processes. These initiatives include 'prebunking,' the practice of proactively exposing people to weakened examples of manipulation tactics to help them build cognitive resistance before they encounter the real thing.

Finally, the business helix appears to engage primarily as a tactical implementation partner. The Diskominfo–Gradasi partnership is a key example, showing business actors being brought in for their specialized expertise to achieve a specific economic goal (increasing MSME sales), rather than running broad public literacy campaigns themselves. While this organic specialization shows adaptability, it also underscores the core thesis: without a central body to strategically weave these distinct efforts together, the actors remain isolated specialists. They are, in effect, forging stronger individual links in a chain that is not connected, thereby failing to build systemic, city-wide resilience.

These emergent roles confirm the theoretical adaptability of the Penta Helix framework. The explicit elevation of "media" as a distinct fifth helix in the Indonesian context, as noted by Subagyo (2021), is clearly visible here, with the media performing a crucial function as an "information power." This finding demonstrates how the conceptual model is adapted in practice to fit the specific needs and strengths of the local institutional landscape, even in the absence of formal coordination. This emergent division of labor is not accidental; rather, it can be understood as a direct and tailored response to the specific, ground-level challenges and vulnerabilities faced by the community, which forms the core of the final theme.

4.4. Theme 4: Community Vulnerability as the Ultimate Stakeholder

This final theme synthesizes the previous findings: the entire ecosystem of digital literacy initiatives in Surakarta is a direct, if uncoordinated, response to the profound and pervasive vulnerability of its citizens in the digital age. The community's pervasive vulnerability is the core reason the Penta Helix actors were involved in the first place, and the failure to address it underscores the high stakes of their fragmented approach. The previous themes—the lack of measurement, fragmentation, and reactive specialization—are not merely academic observations; they are the conditions that allow the causal chain of negative impacts, visualized in Figure 3, to persist.

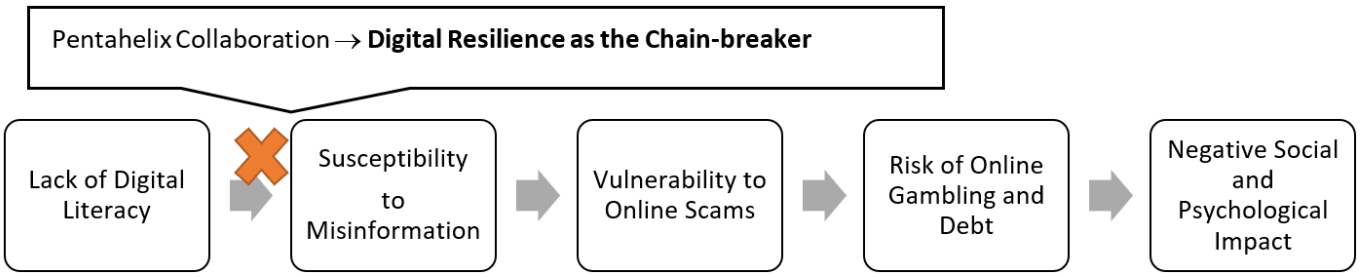

Figure 3 Causal chain of the vulnerability diagram.

A stark picture of this vulnerability is drawn directly from the interview data. According to the PKK representative, many people "tend to believe that information that frequently appears on their social media feed is a fact or the truth"—a powerful illustration of the community's susceptibility to misinformation. This vulnerability is not merely social; it is also economic. In its own performance report, for instance, the Department of Culture and Tourism (Disbudpar) officially identifies a key weakness: a "lack of optimal technical human resources in graphic design, multimedia, and statistics." This is a government admission that digital skills gaps are directly harming the city's economic potential.

When the Penta Helix—the city's supposed collaborative defense mechanism—is fragmented (Theme 2) and lacks a shared definition of success (Theme 1), it cannot act as an effective 'chain-breaker.' The specialized roles that have emerged (Theme 3) are like individual firefighters tackling different parts of a much larger blaze without a central command. They are all doing important work, but they are not working together to put out the fire. The result is that the causal chain continues: a lack of foundational digital literacy leads to vulnerability to misinformation, which in turn can lead to economic loss, social friction, and a decline in civic trust.

This finding firmly connects to the academic literature. The community's struggle aligns directly with what Eshet (2004) termed "information literacy," which he called a "survival skill" for a reason. The situation in Surakarta serves as a case study of what happens when a community's "survival skills" are low and the institutional response is uncoordinated. It underscores the absolute urgency of fostering digital literacy not as a secondary educational goal but as a primary pillar of community well-being and economic development (Rathje et al., 2023). This local struggle to address a fundamental community need connects the specific case of Surakarta to the broader, global ambitions for sustainable development, which are often framed by the Sustainable Development Goals.

4.5. The Implicit Role of the Sustainable Development Goals

A final pivotal finding is that the connection between Surakarta's digital literacy initiatives and the SDGs is largely implicit. While many programs support the SDGs, this alignment is not a stated strategic driver for Penta Helix actors. For example, skills training for MSMEs directly contributes to SDG 8 (Decent Work and Economic Growth), and anti-hoax workshops that build information literacy (Eshet, 2004) bolster SDG 16 (Peace, Justice, and Strong Institutions) by creating a more resilient and informed citizenry. However, these connections are after-the-fact observations rather than core parts of the programs' design and communication (Donati et al., 2023; Rathje et al., 2023).

This situation reflects the broader SDG framework itself, where the "spread of information and communications technology" is celebrated for its potential to "accelerate human progress" (UN, 2015), but digital literacy is not an explicit target. SDG 4, for instance, focuses on "literacy and numeracy," leaving the interpretation of 21st-century skills to local actors. The result in Surakarta is a notable missed opportunity. By not explicitly framing their work within the globally recognized language of the SDGs, Penta Helix actors miss the opportunity to enhance resource mobilization, improve strategic

communication, and foster a more holistic approach to development. The intuitive understanding that digital literacy is important for sustainable development exists, but transitioning this into a formal, strategic component of their collaborative planning is a critical next step. Ultimately, the challenges observed in Surakarta serve as a microcosm of a larger issue, highlighting a notable gap in the SDG framework. This research demonstrates that digital literacy is not merely a 21st-century skill but also a foundational component of sustainable development; as such, it should be explicitly integrated into future global development targets.

5. Conclusions

The Penta Helix model in Surakarta operates not as a formal, coordinated coalition but as a de facto fragmented ecosystem driven by the urgent need to address community-level digital vulnerabilities. The four key findings are synthesized to tell a story of a vibrant but inefficient system. While each helix has naturally specialized in a complementary role, its efforts are hampered by a lack of shared metrics, programmatic silos, and occasional friction between actors. This reality challenges the idealized view of the Penta Helix, revealing a more complex, ground-level dynamic of emergent specialization in the face of collaborative inertia.

The implications of these findings are significant for both theory and practice. For policymakers, this study affirms the critical need to move beyond simply encouraging activity to establish a unified framework for monitoring and evaluation. The 'pockets of collaboration' identified offer a model for more intentional, goal-oriented synergy. Furthermore, explicitly mapping digital literacy initiatives to the SDGs could help prioritize resources and elevate the issue from a technical concern to a core component of sustainable development.

Acknowledging the study's limitations, particularly the data gaps regarding direct collaborative accounts from the business and Academia helices, opens clear avenues for future research. A quantitative study measuring the impact of specific programs on participants' skills and resilience would be a valuable next step to address the 'evaluation gap.' Furthermore, a longitudinal study tracking the evolution of this ecosystem over time could reveal whether the current fragmentation is a temporary phase or a stable feature of the city's governance model. Ultimately, this paper has shown that fostering digital resilience is a complex, multistakeholder endeavor that requires not only the presence of all five helices but also a deliberate and measurable strategy to make them truly collaborate.

Ethical considerations

All participants were informed of the research objectives and voluntarily consented to be interviewed. The use of detailed minutes instead of recordings was an ethical choice to protect participant anonymity and encourage open discussion.
The primary limitation of this study is the data gap regarding direct collaborative accounts from the Academia and Business helices, as detailed in our data source matrix. While their roles were illuminated through documents and other interviews, their own perspectives on specific collaborations were not captured. This limitation is acknowledged and integrated into the analysis, highlighting potential areas for future research.

Conflict of interest

The authors declare that there are no conflicts of interest associated with this publication and that no financial or personal relationships exist that could have influenced the research presented in this paper.

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