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Managing Reciprocal Partnerships for Continuing Agrotechnology Education of Young Farmers

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Abstract: This study aims to analyze and develop a strategic management framework for reciprocal partnerships between non-formal education institutions and the Business and Industrial World (DUDI) to develop Continuing Agrotechnology Education (CAE) for young farmers in Jember Regency. Using a descriptive qualitative approach, data were gathered through in-depth interviews and participatory observations in industrial farmland, with key informants including managers of the Jember Vocational Training Center (BLK), agricultural DUDI practitioners, leaders of millennial farmer groups, and educational and agricultural experts. Qualitative data were analyzed thematically and systematically using the latest *NVivo* software to ensure coding validity and analytical depth. The findings reveal that current non-formal agricultural training remains short-term, fragmented, and poorly aligned with the ongoing digitalization needs of smart farming. This study proposes a framework that develops a CAE management model positioning industry as a co-architect of the curriculum, integrating digital literacy, Internet of Things (IoT) applications, and data-driven farming into non-formal education systems. The study concludes that the empirically grounded reciprocal partnership framework conceptually offers a strategic foundation with the potential to enhance young farmers' dynamic capabilities and functional digital literacy. Consequently, it is recommended that local governments and vocational training providers consider this framework as an operational reference for community empowerment programs in digital agriculture, serving as a basis for empirical validation in future experimental studies.
Keywords: continuing agrotechnology, non-formal education, management, reciprocal partnership, young farmers, digital literacy

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INTRODUCTION

Global digital transformation in the agricultural sector has accelerated a paradigm shift toward Agriculture 4.0, characterized by precision farming, Internet of Things (IoT) applications, and data-driven cultivation systems. At the national level, agricultural digitalization is a priority for strengthening rural productivity and generational regeneration. However, the speed of technological innovation contrasts sharply with the adaptive capacity of farming human resources, particularly young farmers who serve as primary vectors of agricultural modernization. This imbalance indicates that the technological disruption of Agriculture 4.0 is not merely a technical challenge, but fundamentally an educational problem within the non-formal education sector. Conventional adult agricultural training remains

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predominantly episodic, lacking the continuity necessary to convert emerging digital solutions into functional, everyday farm management capabilities. Without institutionalized continuing education frameworks, the structural divide between agrotechnology availability and local human capability continues to widen.

In the agrarian hinterland of Jember Regency, field observations and initial stakeholder dialogues revealed that non-formal vocational programs delivered by the local Vocational Training Center (BLK) and extension agencies remain predominantly static and fragmented. While many young farmers possess smartphones, their usage is largely confined to basic communication and social media, rather than sensor calibration, digital ledger management, or predictive environmental analytics. Preliminary interviews with millennial farmer leaders confirmed that short-cycle workshops rarely translate into sustained field practices because they lack systematic post-training technical assistance. When early digital adopters face software malfunctions or interface complexities, the lack of continuous educational scaffolding often leads them to stop using the technology, resulting in rapid skill decay and low retention of smart farming practices.

Conceptually, addressing these delivery deficits requires re-anchoring agricultural vocational development in the core principles of Non-Formal Education (NFE), adult learning (andragogy), and dynamic capabilities (Hilmi et al., 2026). Andragogical theory posits that adult learners require problem-centered learning designs, experiential tasks, and self-directed applicability to their immediate economic contexts (Yulianingsih et al., 2026). When vocational training centers lack responsive partnership mechanisms with the Business and Industrial World (DUDI), training syllabi fail to keep pace with the rapid technological cycles driven by agribusiness enterprises. In such isolated institutional settings, non-formal education providers cannot function as facilitators of lifelong learning, leaving rural youth disempowered and structurally detached from the expanding industrial agrotechnology ecosystem.

Although previous studies have established the importance of digital literacy and industry linkages in agricultural education, limited research has examined how non-formal education institutions and agricultural industries jointly govern curriculum development, delivery, and post-training mentoring for young farmers. Recent literature on continuing farmer education has largely focused on conceptual models or broad digital-divide syntheses without unpacking operational joint-management mechanisms at the municipal level. Other empirical studies have analyzed indigenous learning or downstream consumer adoption, yet they stop short of evaluating how industry partners and vocational educators co-design competencies for smart agriculture. Consequently, a critical gap remains in understanding how cross-sectoral collaboration can move beyond transactional linkages such as brief internships or hardware donations—toward systemic, reciprocal co-governance in non-formal education systems.

This empirical and theoretical omission necessitates an in-depth qualitative examination of how multi-stakeholder partnerships are structured, negotiated, and enacted. Existing evaluative research tends to measure short-term satisfaction metrics, shedding little light on the relational dynamics, conflicting institutional logics, and shared operational protocols among public training managers, corporate agronomists, and farming youth networks. In particular, the collaborative mechanisms required to position agribusiness enterprises as authentic co-architects of non-formal curricula responsible for joint needs assessments, co-instruction, and continuous field troubleshooting remain insufficiently conceptualized within contemporary non-formal education management literature.

To uncover these complex institutional processes, this study uses a rigorous qualitative analytical procedure to systematically synthesize multiple field narratives and institutional artifacts. The analysis relies on inductive-deductive thematic coding of semi-structured

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interview transcripts, participatory field notes, and formal partnership documents. Open coding was conducted to delineate granular participant accounts regarding curriculum limitations, infrastructural bottlenecks, and institutional role perceptions. Subsequent axial coding structured these concepts into hierarchical categories capturing governance patterns, instructional co-design, and sustained post-training interventions. Selective coding was then performed to synthesize these thematic clusters into a cohesive, empirically grounded partnership model, cross-validating emerging conceptual relationships against field evidence and multi-stakeholder perspectives.

Guided by this empirical gap and analytical orientation, the central research question guiding this investigation is: How can reciprocal partnerships between non-formal education institutions and DUDI be managed to support continuing agrotechnology education for young farmers? To address this primary inquiry comprehensively, three research subquestions are examined: (1) What digital learning and agrotechnology needs are identified among young farmers in the local agricultural ecosystem? (2) How do stakeholders perceive reciprocal partnership roles between non-formal education institutions and industrial enterprises?, and (3) What elements should constitute a continuing agrotechnology education framework that ensures sustained post-training capability?.

Accordingly, this study aims to develop an empirically grounded strategic management framework for reciprocal partnerships between non-formal education institutions and DUDI to develop Continuing Agrotechnology Education (CAE) for young farmers. The theoretical contribution advances Non-Formal Education Management by integrating andragogical principles with reciprocal co-governance and dynamic capability theory in rural industrial contexts. Practically, the study provides an actionable operational reference for vocational training providers, agricultural agencies, and agribusiness leaders to establish institutionalized, lifelong training pathways that foster technological resilience among rural youth.

METHOD

This study employed a descriptive qualitative approach grounded in a case study design (Creswell & J. David Creswell, 2018) to investigate how partnerships between non-formal education institutions and the Business and Industrial World (DUDI) are managed in developing Continuing Agrotechnology Education (CAE) for young farmers. The case study design was selected because it enables an in-depth, contextual exploration of a contemporary, real-world phenomenon within its real-life boundary, specifically focusing on relational dynamics, curriculum co-creation, and organizational governance between vocational training providers and agricultural industries (Yin, 2018). In alignment with this design, the primary unit of analysis was the partnership management process connecting the non-formal education institution, agricultural DUDI, extension services, and young farmer communities. Defining this collaborative process as the analytical unit enables the investigation to scrutinize multi-stakeholder interactions, systemic bottlenecks, and shared institutional commitments that quantitative metrics cannot adequately capture (Denzin & Lincoln, 2017).

The research was conducted in Jember Regency, East Java Province, an agrarian hinterland area purposively selected based on five interrelated case selection criteria: (1) the presence of the Jember Vocational Training Center (Balai Latihan Kerja/BLK) as an established public non-formal education institution actively seeking curriculum transformation; (2) an established operational partnership between the training center and agricultural DUDI enterprises specializing in precision farming and digital supply chain solutions; (3) a demographically significant population of young and millennial farmers serving as regional catalysts for rural agricultural transformation; (4) active yet heterogeneous smart farming

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adoption in the area, specifically involving IoT automated fertigation, greenhouse monitoring, and digital farm management; and (5) the ongoing execution of vocational training programs that exhibited structural post-training continuity deficits. Field data collection and multi-stakeholder engagements spanned six months, from June to November 2026. The primary fieldwork sites comprised BLK Jember, two industrial agribusiness partners, and three millennial farmer communities distributed across key agricultural sub-districts in Jember.

The primary subjects and key informants were selected using a purposive sampling strategy combined with snowball sampling to ensure data richness and representativeness across the institutional ecosystem (Patton, 2015). Selection criteria required informants to have direct involvement, strategic authority, or active participation in agricultural non-formal training programs, digital technology implementation, or partnership policy formulation. The finalized key informants comprised 12 individuals: two executive managers from BLK Jember, three corporate representatives and technical instructors from agricultural DUDI partners, three agricultural extension officers (Penyuluh Pertanian Lapangan/PPL) from the Agricultural Office, and four leaders of millennial farmer groups. The detailed profiles of the key informants are summarized in Table 1.

Table 1. Profile of Key Informants in the CAE Partnership Ecosystem

Informant Code	Institutional Role / Position	Criteria for Selection	Primary Data Contribution
INF-BLK-01	Head of Vocational Training Center (BLK Jember)	Policy maker, >5 years managing non-formal vocational programs	Institutional partnership governance, funding structures, and strategic policies
INF-BLK-02	Senior Instructional Designer at BLK	Curriculum designer, certified vocational trainer	Pedagogical frameworks, course structures, and evaluation systems
INF-DUDI-01	Chief Technology Officer (Smart Farming DUDI)	Industry practitioner, provider of IoT agricultural devices	Industry competence standards, technology integration, co-curriculum inputs
INF-DUDI-02	HR & Partnership Manager (Agribusiness DUDI)	Corporate coordinator for CSR and vocational linkages	Link-and-match mechanisms, internship schemes, market absorptive capacity
INF-DUDI-03	Senior Agronomist & Field Engineer	Technical field instructor for smart farming application	Practical digital literacy needs, field troubleshooting, and hands-on modules
INF-PPL-01	District Agricultural Extension Coordinator	Government extension supervisor, >10 years of field experience	Community readiness, local policy synergy, and field adoption barriers
INF-PPL-02	Digital Agriculture Field Extension Officer	Facilitator for youth farmer digital adoption	Mentoring dynamics, village-level training constraints, and feedback

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INF-FARM-01	Chairman of Millennial Farmer Community A	Youth farmer group leader, practitioner of smart greenhouse	Learner perspectives, digital literacy gaps, and lifelong learning needs
INF-FARM-02	Secretary of Youth Farmer Association B	Youth coordinator for digital marketing and data-driven farming	Peer-to-peer training experience, technology user adoption issues
INF-FARM-03	Lead Mechanic & IoT User (Farmer Group C)	Young farmer specializing in automated irrigation systems	Technical usability, field application challenges, and skill decay factors
INF-FARM-04	Youth Representative in Organic Agritech	Young entrepreneur in digital supply chain management	Market connectivity needs, post-training continuous assistance expectations
INF-EXP-01	Non-Formal Education Management Expert	Academic professor in adult education and partnership management	Conceptual validation, model refinement, and theoretical alignment

Data collection was carried out through a multi-method qualitative approach comprising semi-structured in-depth interviews, direct participatory observations, and document analysis (Swaithes et al., 2023). In-depth interviews were conducted using an interview guide focused on institutional coordination, curriculum alignment, digital literacy obstacles, and continuous learning mechanisms. The researchers conducted participatory observations during smart farming training sessions at BLK Jember and field implementations on industrial farmland to record real-time behaviors, engagement levels, and technology use. Document analysis encompassed vocational training syllabi, memorandum of understanding (MoU) files, agricultural policy briefs, and training evaluation reports.

To establish rigor and ensure trustworthiness, data validity was verified using source and method triangulation, member checking, and an audit trail (Bazeley & Jackson, 2013; Creswell & J. David Creswell, 2018; Lincoln & Guba, 1985). Source triangulation was achieved by cross-verifying perspectives among BLK managers, DUDI practitioners, extension officers, and young farmers. Method triangulation involved cross-examining interview transcripts with observation field notes and official institutional documents. Member checking also involved presenting preliminary interview summaries to key informants to validate accuracy. At the same time, a detailed audit trail documented every analytical step, coding decision, and raw data file.

Qualitative data were analyzed systematically using a reflexive thematic analysis framework (Braun & Clarke, 2006, 2021) operationalized through the iterative data condensation, display, and conclusion-drawing stages of the interactive model (Miles & Huberman, 2014) and facilitated by NVivo software (Jackson & Bazeley, 2019). To ensure analytical consistency and avoid conceptual ambiguity between thematic analysis and grounded theory traditions, coding terminology was strictly anchored in established qualitative data analysis conventions (Saldaña, 2021). Specifically, the analytical procedure progressed through three integrated phases: first-cycle initial coding (generating descriptive labels from empirical textual units), second-cycle pattern and categorical coding (organizing interrelated codes into overarching categories such as reciprocal governance and co-curriculum design), and thematic synthesis (abstracting underlying patterns into the core components of the Continuing Agrotechnology Education model). Primary textual data, including audio-transcribed interviews, participatory field observation notes, and institutional documents, were imported

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directly into NVivo to establish a structured, traceable audit trail (Forero et al., 2018). The software functioned as a supportive analytical environment to systematically manage the code hierarchy, run cross-stakeholder matrix queries QSR, and verify thematic relationships without displacing researcher-driven qualitative interpretation.

The coding process in NVivo followed a three-stage qualitative coding procedure: open coding, axial coding, and selective coding (Li et al., 2025; Saldaña, 2021). In the initial stage, open coding generated descriptive codes capturing raw expressions regarding partnership barriers, curriculum gaps, and digital skill needs (Kerimbayeva et al., 2024). In the axial coding stage, related codes were organized into hierarchical parent nodes representing broader categories, such as "Reciprocal Governance," "Co-Curriculum Architecture," and "Continuous Mentoring." Finally, selective coding integrated these categories into overarching core themes that articulate the reconstructed Continuing Agrotechnology Education (CAE) model.

The thematic visual representation generated through NVivo software analysis maps the interaction pathways among actors and structural components, as illustrated in Figure 1.

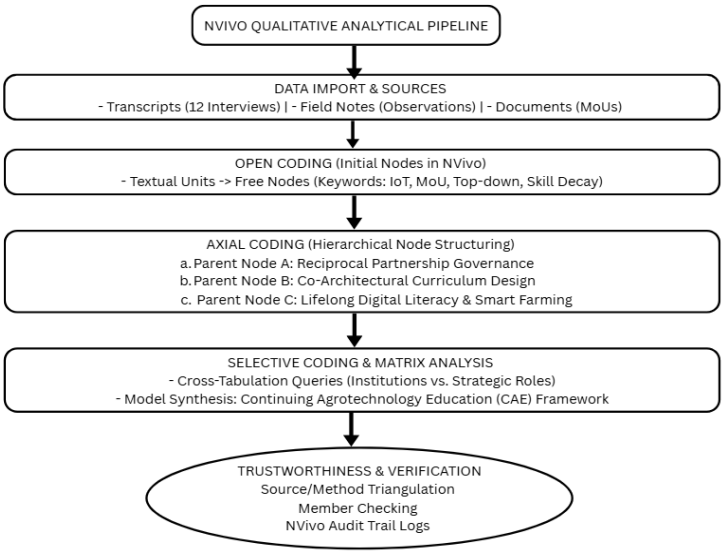


Figure 1. NVivo Qualitative Data Analysis Pipeline for the CAE Model

In addition to thematic coding, I ran matrix coding queries and hierarchy diagrams in NVivo to examine relationships across informant categories and identify thematic patterns (Rossolatos, 2019). Matrix query cross-tabulations compared node references across institutional backgrounds (BLK vs. DUDI vs. Youth Farmers), revealing critical alignment gaps in curriculum expectations. These outputs provided empirical grounding for synthesizing the final reciprocal management framework.

Ethical principles were strictly maintained throughout the research process (Pietilä et al., 2020). The researchers obtained informed consent from all participants before data collection, ensuring voluntary participation, confidentiality, and anonymization of personal identifiers using standardized alphanumeric codes (e.g., INF-BLK-01). Audio recordings and digital transcripts were securely stored in encrypted folders accessible only to the research team, in compliance with institutional human research ethics protocols (Aldridge et al., 2010).

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RESULTS AND DISCUSSION

Results

The qualitative findings of this study, derived from multi-source empirical data comprising in-depth interviews, participatory observations, and institutional documents, were abstracted into three overarching themes governing the partnership management of Continuing Agrotechnology Education (CAE): (1) Structural Disconnects and Digital Literacy Bottlenecks in Existing Training; (2) Reciprocal Governance and DUDI as Co-Architects of Curriculum; and (3) Lifelong Mentoring and Dynamic Capability Enhancement for Young Farmers. These themes emerged through an iterative, three-stage thematic coding procedure in QSR NVivo, moving systematically from granular empirical codes to conceptual categories. First, initial coding captured 83 specific descriptive textual units reflecting participant narratives such as rigid top-down syllabi, lack of IoT hardware maintenance skills, and post-workshop abandonment of technologies. Second, these discrete codes were grouped through pattern coding based on conceptual convergence and co-occurrence across informant groups, consolidating them into sub-thematic nodes (e.g., skill decay, joint competency setting, and village-level learning circles). Finally, through thematic synthesis and constant comparative analysis against the study's research questions and andragogical partnership theories, these sub-nodes were synthesized into the three core parent themes representing the diagnostic baseline, the structural partnership mechanism, and the continuous sustaining ecosystem of the model, respectively. Table 2 summarizes the resulting hierarchical node structure, coding reference frequencies, and data sources across key informant groups generated from NVivo thematic matrix queries.

Table 2. NVivo Thematic Coding Structure and Reference Matrix

Core Theme (Parent Node)	Sub-Themes (Child Nodes)	Reference code	Primary Data Sources
Existing Training Disconnects	Top-down curriculum design	28	INF-BLK-02, INF-FARM-01, INF-FARM-03
	Post-training skill decay & lack of continuity	34	INF-PPL-01, INF-FARM-02, INF-FARM-04
	Infrastructure-capacity imbalance	21	INF-DUDI-01, INF-BLK-01
Reciprocal Governance & Co-Architecture	DUDI co-creation in course design	42	INF-DUDI-01, INF-DUDI-02, INF-BLK-01
	Reciprocal resource-sharing models	31	INF-BLK-01, INF-DUDI-02
	IoT & Data-driven farming integration	39	INF-DUDI-03, INF-FARM-01, INF-EXP-01
Lifelong Mentoring & Capability Building	Peer-to-peer digital learning networks	29	INF-FARM-02, INF-PPL-02
	Dynamic capabilities & adaptation source	26	INF-EXP-01, INF-FARM-04
	Institutionalized post-training SOPs	18	INF-BLK-02, INF-PPL-01

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Structural Disconnects and Digital Literacy Bottlenecks in Existing Training

Empirical observation and cross-stakeholder interview analysis demonstrate that non-formal vocational agricultural training in Jember Regency currently operates in structural isolation from actual industrial needs. Conventional programs offered by local training institutions rely heavily on static, short-term modules that emphasize basic agronomic routines while neglecting data-driven agricultural management. Young farmers reported that although basic digital devices such as smartphones are ubiquitous, their functional digital literacy regarding smart farming technologies such as sensor calibration, automated fertigation, and digital market forecasting remains severely underdeveloped. INF-FARM-01 highlighted this operational disconnect:

> *"We often attend three-day training sessions hosted by government agencies. They teach us smart farming theory using slides, but when we return to the greenhouse, we don't know how to troubleshoot IoT sensors or read soil moisture data logs. Once the training ends, there is no one to consult, so we revert to traditional manual farming." (INF-FARM-01, Personal Communication, July 2026)*

This experiential gap voiced by young farmers was strongly corroborated by industrial practitioners and public training managers. From the perspective of agricultural agribusiness, INF-DUDI-01 confirmed that existing public vocational curricula fail to meet industrial competence benchmarks, observing that *"graduates from standard training programs possess theoretical awareness of digital tools but lack operational diagnostic competencies, which prevents them from handling automated fertigation systems or entering technology-based contract farming"* (INF-DUDI-01, Personal Communication, August 2026). Similarly, INF-BLK-02 admitted internal institutional constraints, acknowledging that *"our training frameworks are bound to standardized government syllabi that are updated infrequently, meaning instructors must prioritize completing predetermined training hours over facilitating customized technological problem-solving"* (INF-BLK-02, Personal Communication, August 2026).

These interview accounts converged directly with field observations and documentary evidence. Participatory observations during agricultural training sessions at BLK Jember revealed that classroom instruction was predominantly lecture-based (occupying over 65% of allocated hours). At the same time, hands-on IoT interface interaction was limited to demonstrations rather than individual troubleshooting. Furthermore, documentary analysis of the official 2024–2025 vocational training syllabi corroborated these pedagogical deficits: learning outcomes were overwhelmingly concentrated on basic manual agronomy (e.g., land preparation, seedbed planting, and conventional fertilization), with no standardized performance indicators dedicated to IoT sensor telemetry, microcontroller diagnostics, or agricultural data analytics. This triangulation across learner narratives, industry feedback, trainer admissions, field observations, and institutional curricula confirms that existing non-formal agricultural training suffers from a systemic disconnect between curriculum delivery and dynamic industrial digitalization.

Furthermore, documentary analysis of past training syllabi confirmed a rigid, one-way pedagogical structure. Training modules were designed without direct input from agribusiness firms, leading to a mismatch between certified skill sets and industry hiring or partnership standards. Representatives from agricultural industries noted that young farmers lack the technocratic mindset needed to maintain digital agricultural hardware and analyze real-time crop metrics.

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Reciprocal Governance and DUDI as Co-Architects of Curriculum

To address these structural bottlenecks, the study developed a reciprocal partnership management framework in which DUDI acts as a Co-Architect of Curriculum rather than a passive external partner. In this model, industrial partners directly identify competence benchmarks, design hands-on digital modules, and co-evaluate participant proficiency. To resolve these structural bottlenecks, the study formulated a reciprocal partnership management framework that transforms DUDI from a passive external recipient into an active "Co-Architect of Curriculum" embedded across the entire educational lifecycle. Rather than providing ad hoc consultation, industrial partners exercise concrete operational responsibilities structured into eight integrated phases: (1) Needs Assessment & Field Diagnostics: DUDI agronomists conduct joint field surveys with BLK instructors to diagnose immediate technological deficits and operational hurdles in local farming practices; (2) Competency Mapping: Industry technical leads formulate competency rubrics aligned with corporate precision agriculture standards, delineating explicit performance indicators for telemetry, automated fertigation, and soil matrix data reading; (3) Curriculum Design: Institutional educators and industrial engineers co-structure the course framework, balancing non-formal andragogical learning principles with commercial agricultural workflows; (4) Module Development: DUDI provides proprietary technical manuals, practical troubleshooting matrices, and open-source software scripts to author hands-on training workbooks; (5) Instructor Provision: Certified corporate field engineers and IoT technicians are deployed alongside public vocational trainers to co-teach diagnostic and hardware troubleshooting sessions; (6) Competency Assessment: Industrial practitioners co-develop scenario-based authentic assessments and evaluate participants' practical execution in simulated greenhouse anomalies; (7) Joint Certification: Successful participants receive co-branded, industry-endorsed certificates that authenticate technical competence for supply chain contracts or agritech enterprise employment; and (8) Continuous Mentoring: DUDI establishes technical support channels and periodic on-farm advisory clinics to guide young farmers through post-training system adoption and field-level equipment maintenance.

> INF-DUDI-01 emphasized this multidimensional operational engagement:
> *"Industry involvement cannot stop at signing an MoU or providing occasional internship placements. As co-architects, we sit with the curriculum team to define the exact diagnostic tasks a farmer must master, supply our field engineers to run practical labs, and directly evaluate whether a trainee can troubleshoot an automated fertigation controller under field conditions. Only when industry standards govern both module design and assessment does vocational education produce capable agrotechnology practitioners." (INF-DUDI-01, Personal Communication, September 2026).*

This systemic operationalization guarantees that curricular content remains tethered to real-time industrial developments while institutionalizing shared accountability between the public vocational center and agribusiness enterprises.

INF-DUDI-01 emphasized the shift from conventional corporate social responsibility (CSR) initiatives to reciprocal co-creation:

> *"Industry cannot just be a destination for student internships or a donor for hardware. We need young farmers who can operate our digital supply chain and IoT infrastructure. By co-designing the CAE curriculum with BLK, we embed our actual field protocols and data standards into the lessons. It is a win-win: farmers gain industry-grade skills, and we secure*

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> *reliable, tech-savvy contract partners." (INF-DUDI-01, Personal Communication, August 2026).*

The reciprocal governance structure balances institutional authority and industrial expertise. While BLK Jember provides certified pedagogical management, facilities, and formal certification, DUDI partners supply updated agrotechnology equipment, cloud-based data platforms, and field engineers as instructors. This structural synergy ensures that curriculum content evolves dynamically alongside advancements in smart agriculture.

Lifelong Mentoring and Dynamic Capability.

The third major finding highlights the need to institutionalize post-training mentoring networks to prevent skill decay and build dynamic capabilities among young farmers. Rather than concluding upon course completion, the reconstructed CAE framework establishes village-level digital learning hubs managed jointly by millennial farmer leaders and field extension officers (PPL). INF-BLK-01 articulated this continuous educational strategy:

> *"The core philosophy of PLS is lifelong learning. Training is merely the initial trigger. Under the CAE model, BLK and DUDI maintain a digital communication gateway and periodic field audits to monitor technology adoption. If a farmer group encounters technical glitches in their automated irrigation systems, DUDI engineers provide real-time digital assistance." (INF-BLK-01, Personal Communication, August 2026).*

Observations across three active millennial farmer groups in Jember Regency comprising a smart greenhouse horticulture collective in Sukorambi, an automated fertigation chili farming group in Wuluhan, and an IoT-based organic vegetable association in Ajung provided concrete evidence that structured peer-to-peer mentoring fosters an agile, self-sustaining learning culture. Fieldwork conducted during bi-weekly technical check-ins revealed dynamic behavioral routines centered on collective digital troubleshooting and collaborative problem-solving. Rather than abandoning smart farming systems when technical glitches occurred, group members actively mobilized around designated youth "farmer champions" who had mastered IoT telemetry and sensor calibration during the advanced CAE training sessions.

During on-site greenhouse monitoring, researchers observed specific peer-assistance practices in action. When automated drip-irrigation solenoid valves malfunctioned due to voltage fluctuations or soil moisture sensor drift in Sukorambi, the local farmer champion (INF-FARM-01) did not call an external technician. Instead, he convened a real-time field diagnostic circle where four fellow young farmers gathered around the central microcontroller box. The champion guided them step by step through checking analog-to-digital converter (ADC) readings, recalibrating capacitive soil moisture probes using open-source diagnostic mobile applications, and testing line pressure. Similarly, in Wuluhan, observation logs recorded peer-led knowledge transfers where youth champions demonstrated how to log diurnal microclimate data (ambient temperature, humidity, and electrical conductivity) onto cloud-based digital dashboards via low-power local Wi-Fi networks.

These participatory interactions reveal that peer champions functioned not merely as instructors, but as accessible, on-the-ground technical scaffolds who translated abstract agrotechnology concepts into localized operational routines. Routine peer troubleshooting reduced downtime for smart farming equipment from several weeks (typical in conventional unassisted programs) to mere hours, directly reinforcing user confidence and preventing skill decay across the farming community. INF-FARM-02 encapsulated this observed behavioral transformation:

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> *"Before we organized our weekly learning hub, a single broken sensor meant the entire smart irrigation stayed shut down because everyone was intimidated by the wiring. Now, when an alert pops up on the phone showing erroneous moisture readings, our champion comes over or walks us through the fix via our WhatsApp troubleshooting group. We diagnose the board together, replace the blown fuse or clean the probe, and get it running immediately. Learning from a peer who faces the same mud and crops makes technology feel manageable rather than foreign." (INF-FARM-02, Personal Communication, September 2026).*

Young farmers who mastered IoT applications served as local digital champions, training older or less tech-literate community members. This participatory dynamic transforms digital literacy from an isolated skill into a collective community capability. The overall synthesized framework of Continuing Agrotechnology Education (CAE) is illustrated in Figure 2.

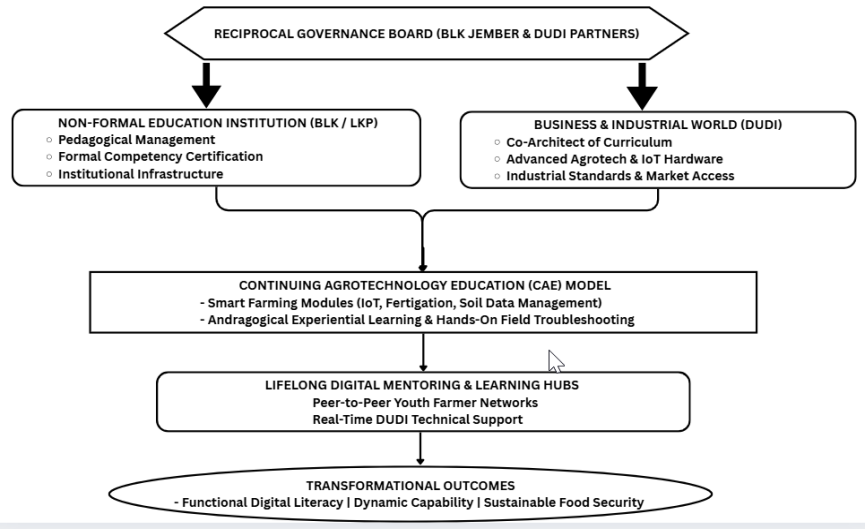


Figure 2. Reconstructed Reciprocal Management Model for Continuing Agrotechnology Education (CAE)

The final Continuing Agrotechnology Education (CAE) framework (Figure 2) is not a speculative conceptual construct, but an inductive-deductive synthesis derived directly from empirical data streams across informants, field observations, and institutional documents. Each structural component within the model corresponds to concrete field challenges, participant demands, and verified institutional practices captured during fieldwork. To ensure methodological transparency and demonstrate that the model is thoroughly grounded in the data, Table 3 delineates the empirical basis, data origins, and analytical synthesis for each core component of the CAE framework. This systematic integration of multiple data sources strengthens the empirical foundation of the framework by establishing clear connections between observed educational practices and the proposed conceptual components. The analytical process further enables the identification of recurring patterns, contextual relationships, and institutional factors influencing the implementation of continuing agrotechnology education. By linking empirical findings with relevant theoretical perspectives, the framework provides a structured explanation of how educational needs, learning processes, and institutional support interact within agricultural learning contexts. Consequently, the CAE framework offers a contextually grounded foundation for informing educational program

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development, institutional strategies, and future empirical investigations in continuing agricultural education.

Table 3. Empirical Grounding and Synthesis Matrix of the Reconstructed CAE Model

Model Component	Empirical Problem / Field Baseline	Data Source & Informant Voice	Synthesized Structural Feature in Model
Reciprocal Governance Board	Isolated planning; BLK bound to rigid state syllabi while DUDI operates with separate commercial tech standards.	Interviews (INF-BLK-01, INF-DUDI-02); Joint MoU documents. "We need a formal joint steering mechanism, not just ceremonial partnerships."	Bi-institutional steering board with shared decision-making authority over training budgets, schedules, and resource allocations
Co-Architect Curriculum Design	Theoretical, lecture-heavy delivery (>65% class time); lack of practical IoT telemetry and sensor diagnostics	Syllabi review (BLK 2024–2025); Interviews (INF-BLK-02, INF-DUDI-01). *"Standard modules don't prepare farmers for real-world automated fertigation."*	8-phase co-design protocol embedding DUDI performance rubrics, hands-on diagnostic lab hours, and joint certification
Smart Farming & IoT Core Modules	Smartphone usage restricted to social media; inability to interpret soil moisture logs or troubleshoot hardware faults	Field observations in greenhouses; Interviews (INF-FARM-01, INF-DUDI-03). *"We couldn't read the microcontroller logs when sensors malfunctioned.*	Modular learning units prioritizing microcontroller diagnostics, sensor calibration, diurnal climate logging, and data-driven fertigation
Village-Level Learning Hubs & Champions	Rapid post-training skill decay; farmers reverting to conventional manual methods when unassisted.	Observations across 3 farmer groups (Sukorambi, Wuluhan, Ajung); Interviews (INF-FARM-02, INF-PPL-01)	Institutionalized peer-mentoring circles led by local youth champions to conduct real-time field troubleshooting.
Continuous Digital Gateway & Assistance	Complete break in technical support after formal workshop completion.	Interviews (INF-FARM-03, INF-PPL-02, INF-DUDI-01). *"Once the three-day class ended, there was no technician to call*	Real-time digital communication channels connecting farming groups with DUDI field engineers and BLK instructors for remote diagnostics

As synthesized in Table 3, the resulting model reflects an organic alignment between diagnostic field realities and systemic managerial solutions. Youth farmers defined the learning content (demanding hands-on troubleshooting rather than abstract agronomy), industrial partners provided performance benchmarks and technical verification standards, and the non-formal education institution contributed the andragogical framework and certification legitimacy. Integrating these data-driven elements confirms that the CAE model serves as an authentic, evidence-based roadmap for sustaining digital agrotechnology adoption in rural communities.

Discussion

The empirical findings demonstrate that reconstructing non-formal vocational training into a reciprocal partnership model fundamentally addresses the long-standing disconnect between education providers and the agricultural industry (Ariefianto et al., 2026). While the results align with the foundational tenets of Andragogy and Adult Education (Knowles et al., 2020), which posit that adult learners acquire functional competencies most effectively through problem-centered, experiential learning situated in immediate socio-economic realities, this study advances andragogical theory in three distinct ways within the context of digital rural

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transformation: First, it extends the classical andragogical assumption of self-directed learning by introducing the construct of *triadic scaffolding*. Traditional andragogy primarily conceptualizes the learning transaction as an unmediated dyad between the adult educator and the autonomous learner. In complex technocratic environments such as smart agriculture, however, self-directedness alone is insufficient. This research demonstrates that adult learning efficacy requires an institutionalized triad comprising pedagogical facilitators (BLK), industrial technical co-architects (DUDI), and grassroots peer champions.

Second, the study redefines experiential learning in rural non-formal education by shifting the locus of practice from retrospective adult reflection to *real-time diagnostic co-troubleshooting*. Rather than viewing adult learning simply as the accumulation and personal reflection upon past experiences, the CAE framework reveals that digital capability formation occurs through immediate, collaborative crisis intervention specifically when diagnosing sensor anomalies, reading telemetry errors, or recalibrating microcontrollers in working greenhouses. Third, this research contributes to adult education literature by bridging individual andragogical empowerment with organizational *Dynamic Capabilities*. While classic adult learning theory focuses largely on individual cognitive growth and psychosocial transformation, the CAE model demonstrates how andragogical principles can be scaled into a collective community capability. By establishing village-level peer learning hubs, the model shows that adult learning becomes an institutionalized, socialized asset that enhances the absorptive and adaptive capacities of farming collectives facing rapid technological disruption. Traditional top-down, classroom-based vocational programs fail precisely because they strip adult learning of this socio-technical scaffolding, reducing transformative adult education to passive didactic consumption.

Conceptualizing DUDI as a "Co-Architect of Curriculum" extends partnership theories within Non-Formal Education Management by redefining the boundaries of industrial participation. Previous studies by Yusri and Kurniawan (2021) and Hufad et al. (2022) emphasized the importance of link-and-match schemes between vocational institutions and industry. However, conventional partnership models predominantly position industry in the downstream phase as passive consumers of graduates, hosts for short-term internships, or donors of surplus equipment. In this conventional arrangement, curriculum design authority remains unidirectional and is monopolized by public training centers that rely on static government syllabi, resulting in persistent field-level competence mismatches.

In contrast, the CAE model advanced in this study shifts this dynamic to upstream, reciprocal co-governance. Rather than entering the process post-training, industrial enterprises participate directly from the inception of program planning. DUDI agronomists and engineers conduct joint field diagnostics, co-formulate competency rubrics, develop troubleshooting modules, co-instruct in practical sessions, and conduct authentic competency evaluations. Table 4 illustrates the structural and operational contrasts between the conventional vocational training partnership and the reciprocal CAE model.

From a theoretical standpoint, integrating the concept of *Dynamic Capabilities* (Teece, 2019) into Non-Formal Education management illuminates how young farmers systematically adapt to disruptive digital environments in the industrial agricultural sector. Rather than treating dynamic capabilities as an abstract organizational construct, the empirical data reveal that the Continuing Agrotechnology Education (CAE) framework operationalizes all three core micro-foundations of dynamic capabilities: sensing, seizing, and transforming. (1) Sensing (Identifying Opportunities and Market Demands): Young farmers developed the capacity to identify precision farming innovations and interpret changing market parameters. Empirical interview narratives showed that after CAE training, participants used digital market aggregators, agricultural meteorological portals, and localized soil sensors to anticipate weather volatility and high-value commodity demand. As INF-FARM-01 articulated, "We learned to identify market signals through data dashboards; when demand for premium greenhouse melon

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rises, we evaluate which digital microclimate sensors need to be installed in our plots to ensure standardized crop sweetness and grade quality" (INF-FARM-01, Personal Communication, August 2026). (2) Seizing (Technology Mobilization and Digital Adoption): Farmers mobilized resources to deploy smart farming infrastructure, execute data-driven farm operations, and integrate into digital supply networks. Field observations in Sukorambi and Wuluhan recorded young farmers installing microcontroller-based automated fertigation controllers, calibrating capacitive soil moisture probes, and analyzing diurnal electrical conductivity (EC) values directly from mobile interfaces. Furthermore, groups gained commercial advantages by bypassing mediators and logging harvest metrics into shared spreadsheets to supply contracted agribusiness DUDI partners directly. (3) Transforming (Reconfiguring Routines and System Maintenance): The young farmers fundamentally restructured conventional farming routines into precise, digitally monitored agronomic systems while establishing autonomous hardware maintenance capabilities. Observational logs and documentary evidence documented a complete transition from manual guesswork and handwritten logs to automated smartphone irrigation timers and cloud-hosted cultivation databases. Critically, when system anomalies occurred, such as solenoid valve signal drops or telemetry errors, farmers demonstrated transformative troubleshooting practices: rather than disengaging from the technology, they convened real-time diagnostic circles with village champions to recalibrate boards and restore system operations.

The empirical manifestation of sensing, seizing, and transforming confirms that the CAE model extends beyond conventional hardware distribution. By fostering these dynamic capabilities through reciprocal partnership scaffolding, non-formal education equips adult learners to recognize technological opportunities, mobilize digital agricultural resources, and continuously reconfigure farming operations amidst rapid industry disruption, substantiating the theoretical claims of Rotz et al. (2019) (2019) and OECD (2023).

Furthermore, the continuous mentoring mechanism established in the CAE framework directly resolves the critical challenge of post-training skill decay through the lens of lifelong learning and reciprocal governance. Rather than treating learning as an episodic event terminating with course completion, the framework operationalizes adult education as an ongoing socio-technical process anchored in rural communities. By embedding local millennial farmer leaders as digital champions within village-level learning hubs, the CAE model institutionalizes peer-based problem-solving and collective knowledge sharing. When technological disruptions occur, young farmers do not disengage; instead, they mobilize existing social capital and communal learning structures to troubleshoot technical errors collaboratively. This community-anchored mechanism reinforces the findings of Hilmi et al. (2023) regarding the efficacy of localized support structures in sustainable rural empowerment, proving that sustaining agrotechnology adoption requires institutionalizing continuous, peer-led dynamic capability enhancement rather than relying on isolated training workshops.

This study's practical implications are directly actionable for vocational education managers, policymakers, and industry stakeholders. For managers of Balai Latihan Kerja (BLK) and private training providers (LKP), this research offers a concrete operational blueprint for restructuring vocational curricula through joint steering committees with industry partners. For local governments, particularly Agricultural and Manpower Offices, the findings underscore the need to allocate budget lines for post-training mentorship networks rather than concentrating resources solely on short-term training events. Rather than asserting definitive transformation, the proposed framework can inform the development of partnership standard operating procedures (SOPs) that can support the digital transformation of rural youth, encourage young talent retention in the agrifood sector, and contribute to regional food security initiatives.

Despite its comprehensive insights, this study has limitations. The qualitative case study design was focused specifically on Jember Regency, an agrarian hinterland with unique

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industrial features. Consequently, the empirical findings may reflect local structural characteristics that differ from non-industrial agricultural regions. Future research should pursue multi-case studies across diverse geographic ecosystems and employ quantitative structural equation modeling (SEM) to measure the precise impact of the CAE model on farm productivity, income growth, and long-term technology retention rates among young farmers.

CONCLUSION

This study concludes that reciprocal partnerships between non-formal education institutions (such as BLKs) and the Business and Industrial World (DUDI) may provide a mechanism to address structural disconnects in vocational agricultural training for young farmers. By positioning industry as a co-architect of the curriculum, the reconstructed Continuing Agrotechnology Education (CAE) framework proposes a coherent pathway to integrate smart farming, IoT applications, and data-driven cultivation into non-formal education systems. The primary theoretical contribution expands the understanding of non-formal education management from provider-centered management to multi-stakeholder reciprocal governance, illustrating how adult learning principles and dynamic capability building can be jointly scaffolded in rural industrial environments. Practically, the framework highlights the potential of village-level digital learning hubs and youth-led peer mentoring networks to mitigate post-training skill decay. From a policy standpoint, local authorities and vocational providers are encouraged to consider this reciprocal model when designing standard operating procedures (SOPs) for agrotechnology empowerment initiatives. Because this study remains qualitative and exploratory, future research should test the empirical validity and implementation of the proposed CAE model through multi-case comparative designs across diverse agro-ecological zones and utilize quantitative structural equation modeling (SEM) to measure its longitudinal impact on farm productivity, economic returns, and technology retention among young farmers.

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