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Managing Reciprocal Partnerships for Continuing Agrotechnology Education of Young Farmers

Lutfi Ariefianto[1]*, Arief Tukiman Hendrawijaya[2], Didik Kurniawan[3], Arini Milla Chanifa[4], Nurul Faizah[5]
[1,2,3,4]Universitas Jember, Indonesia
[5]Ankara University, Turkey
*Author Correspondence. Email: lutfipls.fkip@unej.ac.id, Phone: +6282140077111

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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 of a CAE management model where industry has a role as a co-architect of the curriculum by including digital proficiency, 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

The global digital transformation of the agricultural sector has accelerated a paradigm shift to Agriculture 4.0, marked by precision farming, IoT applications and data-driven cultivation systems. The digitalisation of agriculture is a national priority, for rural productivity and generational regeneration (Ronzhin et al., 2025). Nevertheless, the pace of technological innovation is inconsistent with the adaptive capacity of farming human resources, especially young farmers, who are the main vectors of agricultural modernisation (White, 2012). This imbalance shows that the technological disruption of Agriculture 4.0 is not only a technical challenge, but essentially an educational problem within the non-formal education sector (Iredale, 1978). Traditional adult agricultural training is often episodic and lacks the continuity

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needed to translate emerging digital solutions into usable, everyday farm management capabilities (Cambra Baseca et al., 2019). This structural gap between the availability of agrotechnology and local human capability continues to widen in the absence of institutionalised frameworks for continuing education.

Field observations and preliminary stakeholder dialogues in the agrarian hinterland of Jember Regency show that non-formal vocational programs organised by the local Vocational Training Center (BLK) and extension agencies are still largely static and fragmented (Hilmi et al., 2026). Many young farmers may own smartphones, but their use is primarily for basic communication and social media, not sensor calibration, digital ledger management or predictive environmental analytics. Preliminary interviews with millennial farmer leaders showed that short-cycle workshops rarely result in sustainable field practices because of the lack of systematic technical support following training. Early adopters of digital technologies, when faced with software failures or interface difficulties, often abandon the technology due to a lack of continuous educational support, leading to rapid skill loss and minimal retention of smart farming practices.

Conceptually, the delivery deficits can be addressed by re-anchoring agricultural vocational development to the basic principles of Non-Formal Education (NFE), adult learning (andragogy) and dynamic capabilities (Hilmi et al., 2026). According to andragogical theory, adult learners require problem-centered learning designs, experiential tasks, and self-directed applicability to their immediate economic contexts (Yulianingsih et al., 2026). In the absence of responsive partnership mechanisms with the Business and Industrial World (DUDI), the training syllabi in vocational training centers cannot keep pace with the rapid technological cycles determined by agribusiness enterprises. However, in such isolated institutional settings, non-formal education providers cannot act as facilitators of lifelong learning, leaving rural youth disempowered and structurally disconnected from the expanding industrial agrotechnology ecosystem.

Previous studies have shown the significance of online literacy and industry linkages in agricultural education (Xu et al., 2026). However, there is limited research on how non-formal education institutions and the agricultural industry jointly govern curriculum development, delivery, and post-training mentoring for young farmers. Recent literature on continuing farmer education has been largely focused on conceptual models or broad digital-divide syntheses, without unpacking operational joint-management mechanisms at the municipal level. Other empirical studies have looked at indigenous learning or downstream consumer adoption. But they do not go as far as to assess how industry partners and vocational educators co-design competencies for smart agriculture. Hence, there remains a crucial gap in understanding how collaboration across sectors can move beyond transactional connections such as short-term internships or hardware donations, toward systemic, reciprocal co-governance within non-formal education systems.

This empirical and theoretical gap calls for a more qualitative investigation of how multi-stakeholder partnerships are structured, negotiated and enacted. The evaluative studies that exist tend to focus on short-term satisfaction indicators and do not tell much about the relationships, the clashing institutional logics and common operational rules that exist between public training managers, corporate agronomists and networks of young farmers. More specifically, non-formal curriculum management literature is not well-conceptualised around the collaborative mechanisms that would allow agribusiness enterprises to become true co-architects of non-formal curricula, responsible for joint needs assessments, co-instruction and ongoing field troubleshooting (Junmei Wu, 2026).

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A rigorous qualitative analytical procedure is used in this study to systematically synthesise multiple field narratives and institutional artefacts to reveal these intricate institutional processes. The analysis is based on inductive-deductive thematic coding of semi-structured interview transcripts, participatory field notes and formal partnership documents (Stellato et al., 2026). Open coding was used to describe in detail participant descriptions of curriculum constraints, infrastructural bottlenecks, and institutional role perceptions. After axial coding, these concepts were grouped into hierarchical categories of governance patterns, instructional co-design, and sustained post-training interventions (Taneo et al., 2026). Then, selective coding was applied to integrate these thematic clusters into an empirically grounded partnership model, cross-validating emerging conceptual relationships with field evidence and multi-stakeholder perspectives.

This empirical gap and analytical orientation guide this investigation into the central research question: How can reciprocal partnerships between non-formal education institutions and DUDI be managed to support continuing agrotechnology education for young farmers? To provide a comprehensive answer to this main question, three research sub-questions are examined: (1) What are the identified digital learning and agrotechnology needs of young farmers in the local agricultural ecosystem? (2) What are the views of stakeholders on the reciprocal roles of non-formal education institutions and industrial enterprises in partnership?, and (3) What should be the components of a framework for continuous agrotechnology education that will ensure post-training capability?

Therefore, this study aims to develop an empirically-based strategic management framework for non-formal education institutions and DUDI reciprocal partnerships to develop Continuing Agrotechnology Education (CAE) for young farmers. The study's theoretical contribution to Non-Formal Education Management is the integration of andragogical principles with reciprocal co-governance and dynamic capability theory within the framework of rural industrial settings. Practically, the study provides an operational reference for vocational training providers, agricultural agencies, and agribusiness leaders to establish institutionalised lifelong training pathways that enhance technological resilience among rural youth.

METHOD

This research used a qualitative descriptive approach with a case study design (Creswell, J. W., 2018) to explore the management of partnerships between non-formal education institutions and the Business and Industrial World (DUDI) in developing Continuing Education of Agrotechnology (CAE) for young farmers. The case study design was selected because it allows for an in-depth, contextual analysis of a contemporary, real-life phenomenon within its natural boundary, emphasising relational dynamics, curriculum co-creation and organisational governance between vocational training providers and agricultural industries (McCorcle & Bell, 1986). In line with this design, the partnership management process between the non-formal education institution, agricultural DUDI, extension services and young farmer communities was the main unit of analysis. Using this collaborative process as the unit of analysis, the study can explore multi-stakeholder interactions, systemic bottlenecks and shared institutional commitments that cannot be captured by quantitative measures (Ho et al., 2007).

The research was conducted in the Jember Regency, East Java Province, a purposively chosen agrarian hinterland area based on five interrelated criteria for case selection: (1) the existence of the Jember Vocational Training Center (Balai Latihan Kerja/BLK) as a formal public non-formal education institution that actively seeks to transform its curriculum; (2) an established operational partnership between the training center and agricultural DUDI enterprises specialising in precision farming and digital supply chain solutions; (3) a

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demographically significant population of young and millennial farmers who act as regional catalysts for rural agricultural transformation; (4) the active yet heterogeneous adoption of smart farming practices in the area, specifically involving IoT automated fertigation, greenhouse monitoring, and digital farm management; and (5) the ongoing implementation of vocational training programs that exhibited structural post-training continuity deficits. Field data collection and multi-stakeholder engagements were conducted for a duration of 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 main subjects and the key informants were selected via purposive sampling and snowball sampling to ensure the richness and representativeness of data in 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 total number of key informants identified was 12 people, including two executive managers of 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. Table 1. Detailed profiles summary of the key informants.

Table 1.Profile of Key Informants in 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

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INF-PPL-02	Digital Agriculture Field Extension Officer	Facilitator for youth farmer digital adoption	Mentoring dynamics, village-level training constraints, and feedback
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 undertaken using a multi-method qualitative approach including semi-structured in-depth interviews, direct participatory observations and document analysis (Swaithes et al., 2023). In-depth interviews were conducted based on an interview guide covering institutional coordination, curriculum alignment, barriers to online literacy, and continuous learning mechanisms. Researchers conducted participatory observations during smart farming training at BLK Jember and field implementation on industrial farmland to record real-time behaviours, engagement levels, and technology use. The document analysis comprised vocational training syllabi, memorandum of understanding (MoU) files, agricultural policy briefs and training evaluation reports.

Data validity was confirmed using source and method triangulation, member checking, and an audit trail to ensure rigour and trustworthiness (Bazeley, P., & Jackson, 2013); (Creswell, J. W., 2018); (Lincoln, Y. S., & Guba, 1985)). Source triangulation was done by cross verifying perspectives of the BLK managers, DUDI practitioners, extension officers and young farmers. Method triangulation was the cross-examination of interview transcripts with observation field notes and official institutional documents. Member checking also included sharing preliminary interview summaries with key informants to ensure their accuracy. Simultaneously, a comprehensive audit trail documented every analytical step, coding decision, and raw data file.

The qualitative data were systematically analysed within the reflexive thematic analysis framework (Braun, V., & Clarke, 2006) operationalised through the iterative stages of data condensation, display, and conclusion drawing of the interactive model (Miles, M. B., & Huberman, 2014) and facilitated by NVivo software (Jackson, K., & Bazeley, 2019). Coding terminology was firmly rooted in the conventions of established qualitative data analysis (Saldaña, 2021) to ensure analytical consistency and to avoid conceptual confusion between thematic analysis and grounded theory traditions. More precisely, the analysis involved three interrelated steps: (a) first-cycle open coding (developing descriptive labels from empirical units of text); (b) second-cycle pattern and categorical coding (collapsing related codes into more

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comprehensive categories such as reciprocal governance and co-curriculum design); and (c) thematic synthesis (abstracting underlying patterns into core elements of the Continuing Agrotechnology Education model). Primary textual data such as audio-transcribed interviews, participatory field observation notes and institutional documents were imported directly into NVivo creating a structured and traceable audit trail (Forero et al., 2018). The software also provided an analytic environment for systematically managing code hierarchies, running cross-stakeholder matrix queries (QSR), and checking thematic relationships without displacing researcher-driven qualitative interpretation.

The coding process was performed in NVivo using the three-stage qualitative coding procedure, namely open coding, axial coding and selective coding (Saldaña, 2021; (Li et al., 2025). Stage one: Open coding generated descriptive codes that represented explicit statements about barriers to partnership, gaps in the curriculum, and needs for digital skills (Kerimbayeva et al., 2024). During the axial coding phase similar codes were grouped into hierarchical parent nodes representing more general categories such as "Reciprocal Governance", "Co-Curriculum Architecture" and "Continuous Mentoring". Finally, selective coding integrated the categories into overarching core themes that express the reconstructed Continuing Agrotechnology Education (CAE) model.

Thematic visual representation generated through NVivo software analysis shows the pathways of interaction among actors and structural elements (see Figure 1).

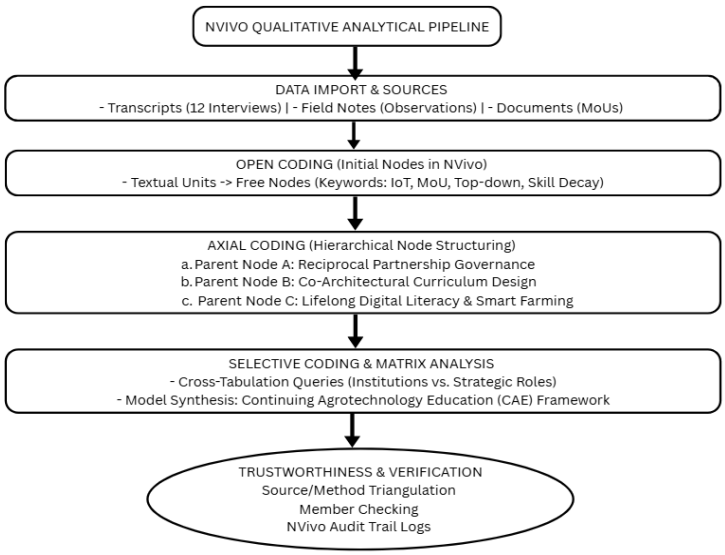


Figure 1. NVivo Qualitative Data Analysis Pipeline for the CAE Model

Besides thematic coding, I employed matrix coding queries and hierarchy diagrams in NVivo to explore connections 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 gaps in alignment of curriculum expectations. These outputs provided empirical support for the synthesis of the final reciprocal management framework.

Ethical principles were strictly observed in the whole research process (Pietilä et al., 2020). All participants gave informed consent before data collection, participation was voluntary, confidentiality and anonymisation of personal identifiers were guarantyd by standardised alphanumeric codes (e.g. INF-BLK-01). Audio recordings and digital transcripts

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were stored securely in encrypted folders accessible only to the research team, in line with institutional human research ethics protocols (Aldridge et al., 2010).

RESULTS AND DISCUSSION

Results

The qualitative findings of this study, abstracted from multi-source empirical data (in-depth interviews, participatory observations, and institutional documents), were organised into three overarching themes that govern the partnership management of Continuing Agrotechnology Education (CAE): (1) Structural disconnects and technological 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. The themes were developed through an iterative three-stage thematic coding process using QSR NVivo, moving systematically from granular empirical codes to conceptual categories. Coding was initially used to identify 83 descriptive textual units that represented participant stories (e.g., rigid top-down syllabi, lack of IoT hardware maintenance skills, and abandonment of technologies after the workshop). Second, the discrete codes were aggregated by pattern coding according to conceptual convergence and co-occurrence across informant groups and consolidated into sub-thematic nodes (e.g., skill decay, joint competency setting, village-level learning circles). Finally, through thematic synthesis and constant comparative analysis with the research questions of the study and andragogical partnership theories, these sub-nodes were synthesised into the three core parent themes of the model, namely the diagnostic baseline, the structural partnership mechanism and the continuous sustaining ecosystem, respectively. Table 2. Summary of resulting hierarchical node structure, coding reference frequencies and data sources across key informant groups produced 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

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	Dynamic capabilities & adaptation source	26	INF-EXP-01, INF-FARM-04
	Institutionalized post-training SOPs	18	INF-BLK-02, INF-PPL-01

Current Training: Structural Disconnects and Online Literacy Bottlenecks

Empirical observations and cross-stakeholder interview analyses show that non-formal vocational agricultural training in Jember Regency is currently structurally isolated from actual industrial needs. Traditional programs of local training institutions are heavily based on static, short-term modules focusing on basic agronomic routines, but neglecting data-driven agricultural management. Young farmers said they have access to basic electronic devices like smartphones, but they still have a very poor command of smart farming technologies like sensor calibration, automated fertigation, and digital market forecasting. INF-FARM-01 referenced this operational disconnect:

> *" We often attend three-day trainings put on by government agencies. They teach us smart farming theory with slides, but when we return to the greenhouse we don't know how to troubleshoot IoT sensors or read the soil moisture data logs. "But training is over, there is no one to ask, so we go back to the traditional farming manual." (INF-FARM-01, Personal Communication, July 2026).*

The experiential gap expressed by young farmers was strongly corroborated by industrial practitioners and public training managers. From an agricultural agribusiness perspective, INF-DUDI-01 confirmed that existing public vocational curricula do not align with industrial competence benchmarks, noting that "graduates from standard training programs have theoretical awareness of digital resources 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). Likewise, INF-BLK-02 referenced internal institutional constraints, stating "our training frameworks are tied to standardised government syllabi that are updated infrequently, meaning instructors must prioritise completing predetermined training hours over facilitating customised technological problem-solving" (INF-BLK-02, Personal Communication, August 2026).

These interview accounts dovetailed directly with field observations and documentary evidence. Participatory observations at BLK Jember during the agricultural training sessions showed that the classroom instruction was mainly lecture-style (more than 65% of allocated hours). At the same time, practical interaction with IoT interfaces was limited to demonstrations, rather than individual troubleshooting. Furthermore, documentary analysis of the official 2024–2025 vocational training syllabi corroborated these pedagogical shortcomings: learning outcomes were overwhelmingly focused on elementary manual agronomy (e.g., land preparation, seedbed planting and conventional fertilisation), without standardised performance indicators targeting IoT sensor telemetry, microcontroller diagnostics or agricultural data analytics. Triangulating the narratives of the learners, feedback of the industry, trainer's admissions, field observations and institutional curricula proves that the existing non-formal agricultural training is plagued with a systemic disconnect between curriculum delivery and dynamic industrial digitalisation.

Furthermore, documentary analysis of prior training syllabi indicated a rigid pedagogical structure in one direction. Agribusiness firms were not involved in the design of training modules, creating a gap between the skills certified and the standards for hiring or partnering

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with the industry. Agricultural industry representatives have noted that young farmers lack the technocratic mindset needed to maintain digital agricultural hardware and analyse real-time crop metrics.

Reciprocal Governance and DUDI: Co-Architects of Curriculum

To overcome these structural bottlenecks, the study developed a reciprocal partnership management framework where DUDI is a Co-Architect of Curriculum, not a passive external partner. In this model, industrial partners directly identify competence benchmarks, develop hands-on digital modules and co-evaluate the proficiency of participants. To overcome these structural bottlenecks, the study developed a reciprocal partnership management framework that transforms DUDI from a passive external recipient to an active "Co-Architect of Curriculum" embedded across the entire educational lifecycle. Rather than providing ad hoc consulting, industrial partners have real operational responsibilities, in eight integrated phases: (1) Needs Assessment & Field Diagnostics: Joint field surveys by DUDI agronomists and BLK instructors identify immediate technological deficits and operational hurdles in local farming practices; (2) Competency Mapping: Industry technical leads design competency rubrics in line with corporate precision agriculture standards, mapping explicit performance indicators for telemetry, automated fertigation and soil matrix data reading; (3) Curriculum Design: Institutional educators and industrial engi (5) Provision of instructors: Certified corporate field engineers and IoT technicians are sent together with public vocational trainers to co-teach diagnostic and hardware troubleshooting sessions; (6) Competency Assessment: Industry practitioners and participants collaboratively design scenario-based authentic assessments, and participants' practical performance is evaluated in simulated greenhouse anomalies; (7) Joint Certification: Successful participants receive co-branded, industry-endorsed certificates that validate technical competence for supply chain contracts or employment in agritech enterprise; and (8) Continuous Mentoring: DUDI establishes technical support channels and regular on-farm advisory clinics to mentor young farmers through post-training system adoption and field-level equipment maintenance.

INF-DUDI-01 underscored this multidimensional operational engagement:

"Industry involvement can't just be about signing MOUs or offering a few internship places now and then. As co-architects we sit with the curriculum team to define the exact diagnostic tasks a farmer must master, have our field engineers run practical labs and directly assess if a trainee can troubleshoot an automated fertigation controller under field conditions. Industry norms should govern both module design and assessment to produce competent agrotechnology practitioners through vocational education." (INF-DUDI-01, Personal Communication, September 2026).

The systemic operationalisation ensures that the curricular content is aligned with the current industrial developments, and it institutionalises the shared accountability between the public vocational center and agribusiness companies.

INF-DUDI-01 highlighted the transition from traditional corporate social responsibility (CSR) initiatives to reciprocal co-creation:

" Industry must not be simply a place where students do internships or a donor of hardware. "We need young farmers who can work our digital supply chain and IoT infrastructure. Through co-designing the CAE curriculum with BLK, we are embedding our real-world field

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> *protocols and data standards into the lessons. It's a win-win situation. Farmers get industry skills and we get reliable, tech-savvy contract partners. (Personal Communication, INF-DUDI-01, August 2026).*

The reciprocal governance structure balances institutional authority with industry expertise. BLK Jember provides certified pedagogical management, facilities and formal certification. DUDI partners provide the latest agrotechnology equipment, cloud-based data platform and field engineers as trainers. This structural synergy ensures that the curriculum content dynamically evolves with the progress in smart agriculture.

Lifelong Mentoring and Dynamic Capability.

The third major finding is the need to institutionalise post-training mentoring networks to prevent skill decay and build dynamic capabilities among young farmers. Rather than ending with the course, the reconstructed CAE framework establishes village-level digital learning hubs co-managed by millennial farmer leaders and field extension officers (PPL). This continuing training strategy was defined in INF-BLK-01:

> *" The basic philosophy of PLS is life long learning. "Training is just the first spark. BLK and DUDI maintain a digital communication gateway and periodic field audits to track technology adoption under the CAE model. When a farmers' group faces 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 including a smart greenhouse horticulture collective in Sukorambi, an automated fertigation chilli farming group in Wuluhan and an IoT-based organic vegetable association in Ajung gave concrete evidence that structured peer-to-peer mentoring builds an agile, self-sustaining learning culture. The bi-weekly technical check-ins enabled fieldwork that showed dynamic behavioural routines focused on collective digital troubleshooting and collaborative problem-solving. Instead of abandoning smart farming systems due to technical glitches, group members actively mobilised around designated youth "farmer champions" who had mastered IoT telemetry and sensor calibration during the advanced CAE training sessions.

Researchers saw some of those peer-assistance practices in action through on-site monitoring of the greenhouses. In Sukorambi, the local farmer champion (INF-FARM-01) did not call in an external technician when automated drip-irrigation solenoid valves malfunctioned due to voltage fluctuations or soil moisture sensor drift. Instead he called for a real time field diagnostic circle as four other 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.

The participatory interactions revealed that peer champions were not simply instructors, but were accessible, on-the-ground technical scaffolds that translated abstract agrotechnology concepts into localised operational routines. Routine peer troubleshooting reduced smart farming equipment downtime from weeks, as seen in traditional unassisted programs, to hours, thereby directly strengthening user confidence and preventing skill decay throughout the farming community. This noted behavioural alteration was captured by INF-FARM-02:

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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. But then, when an alert appears on the phone showing faulty moisture readings, our champion comes over or talks us through the fix on our WhatsApp troubleshooting group. We troubleshoot the board together, change the blown fuse or clean the probe and get it going right away. "When you learn from a peer who is in the same mud and crops, technology feels approachable, not alien." (Personal Communication, Sept. 2026, INF-FARM-02).*

Young farmers became local digital champions, able to master the IoT applications and train older or less tech-savvy members of the community. This participation dynamic makes online literacy a community capability, not a solitary skill. Figure 2 shows the overall synthesised framework of Continuing Agrotechnology Education (CAE).

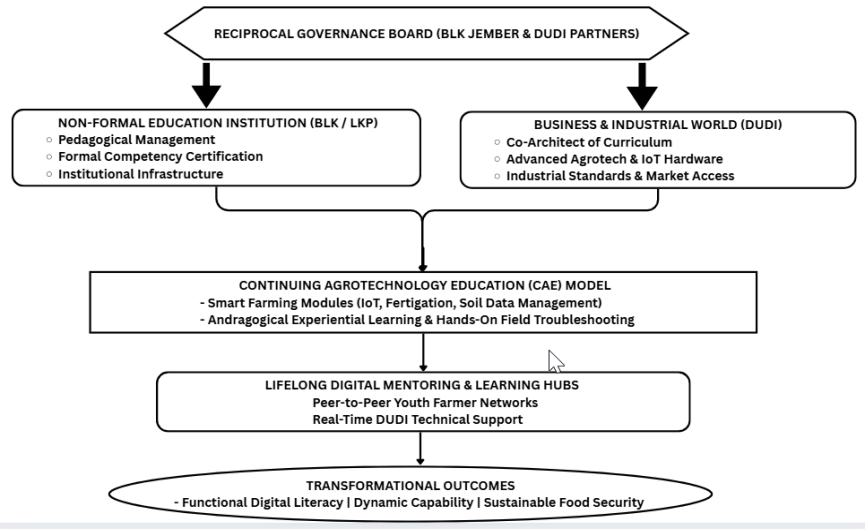


Figure 2. Reconstructed Reciprocal Management Model for Continuing Agrotechnology Education (CAE)

The final Continuing Agrotechnology Education (CAE) framework (Figure 2) is not a speculative conceptual construct but an inductive-deductive synthesis drawn directly from empirical data streams across informants, field observations and institutional documents. Each structural element of the model is associated with real field problems, participant demands and proven institutional practices encountered during fieldwork. To enhance methodological transparency and to show that the model is well-supported by the data, Table 3 details the empirical grounding, data sources, and analytic synthesis of each element of the CAE framework. The systematic inclusion of multiple data sources strengthens the empirical basis of the framework by establishing clear linkages between observed educational practices and the conceptual elements proposed. The analytical process also helps to identify recurring patterns, contextual relationships and institutional factors affecting the implementation of continuing agrotechnology education. The framework connects empirical findings with relevant theoretical perspectives, offering a structured explanation of the interaction of educational needs, learning processes and institutional support in agricultural learning contexts. Thus, the CAE framework offers a contextually grounded rationale to guide the development of educational programs, institutional strategies, and future empirical research in continuing agricultural education.

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Table 3. Synthesis matrix and empirical grounding 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

Synthesis of Table 3 results with the organic alignment of realities of diagnostics' fields with managerial solutions of the system. The youth farmers defined the content of the learning (hands-on troubleshooting rather than abstract agronomy), industrial partners provided the performance benchmarks and technical verification standards and the non-formal education institution provided the andragogical framework and certification legitimacy. The integration of these data-driven aspects affirms the CAE model as a genuine, evidence-driven roadmap for sustaining digital agrotechnology adoption in rural communities.

Discussion

The empirical findings show that the reconstruction of non-formal vocational training into a reciprocal partnership model is a fundamental solution to the long-standing gap between education providers and the agricultural industry (Ariefianto et al., 2026). The findings are consistent with the basic principles of Andragogy and Adult Education (Knowles, M. S., Holton, E. F., III, & Swanson, 2020) which argue that adult learners learn functional competencies most effectively through problem-centered, experiential learning within their immediate socio-economic realities. However, this study contributes to andragogical theory in three ways within the framework of digital rural transformation: Firstly, it extends the classical andragogical assumption of self-directed learning by introducing the construct of triadic scaffolding. Most traditional andragogy sees the learning transaction as an unmediated dyad between the adult

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educator and the autonomous learner (Pratt, 1988). However, in complex technocratic settings such as smart agriculture, self-directedness alone is not sufficient. The study indicates the need for institutionalised triad for effective adult learning, including pedagogical facilitators (BLK), industrial technical co-architects (DUDI) and grassroots peer champions.

Second, the study reconceptualises experiential learning in rural non-formal education by moving the locus of practice from retrospective adult reflection to real-time diagnostic co-troubleshooting. According to the CAE framework, the formation of digital capabilities is not only in the case when adult learning is defined as a process of gathering and reflecting on previous experiences. The formation of digital capabilities is in the moment of collaborating in a crisis, especially when you diagnose sensor anomalies, read telemetry errors or recalibrate microcontrollers in working greenhouses. Third, this research contributes to the adult education literature by linking individual andragogical empowerment to organisational Dynamic Capabilities. Traditional adult learning theory emphasises individual cognitive development and psychosocial transformation. The CAE model illustrates how the andragogical principles can be expanded into a community capability. The model shows that the institutionalised and socialised adult learning asset is created by peer learning hubs at the village level, which increases the absorptive and adaptive capacity of farming collectives in the face of 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.

By conceptualising DUDI as a "Co-Architect of Curriculum," the concept pushes partnership theories in Non-Formal Education Management to new limits by redefining the boundaries of industrial participation. This is in line with previous studies by which emphasised the need for link and match schemes between vocational institutions and industry (Yoto et al., 2024). But traditional partnership models tend to position industry in the downstream phase as passive consumers of graduates, hosts of short-term internships or donors of surplus equipment. In this traditional setting, the authority of curriculum design is one-way and exclusively in the hands of public training centers relying on static government syllabi, resulting in continual field-level competence mismatches.

In contrast, the CAE model presented in this paper shifts this dynamic to upstream, reciprocal co-governance. Industrial enterprises participate directly from the inception of program planning, rather than entering the process after training. Joint field diagnostics by DUDI agronomists and engineers, co-formulation of competency rubrics, development of modules for troubleshooting, co-instruction in practical sessions, and authentic competency evaluations are conducted. Table 4:structural and operational differences between the traditional vocational training partnership and the reciprocal CAE model.

In theory, the inclusion of the concept of Dynamic Capabilities (Teece, 2019) in the management of Non-Formal Education explains the systematic adaptation of young farmers to disruptive digital environments in the industrial agricultural sector. The empirical data suggest that the Continuing Agrotechnology Education (CAE) framework operationalises the three core micro-foundations of dynamic capabilities, i.e., sensing, seizing, and transforming, instead of treating dynamic capabilities as an abstract organisational construct. (1) Sensing (Recognise Market Demands and Opportunities): Young farmers have developed the ability to identify the innovations in precision farming and to interpret changing market parameters. Empirical interview narratives revealed that participants used digital market aggregators, agricultural meteorological portals and localised soil sensors to anticipate weather volatility and demand for high-value commodities post CAE training. As INF-FARM-01 articulated, "we learned to identify market signals through data dashboards, when the demand for premium greenhouse melon rises, we assess which digital microclimate sensors need to be installed in our plots to ensure standardised crop sweetness and grade quality" (INF-FARM-01, Personal Communication,

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August 2026). (2) Grasping (Technology Mobilisation and Digital Adoption): Farmers mobilised resources to deploy smart farming infrastructure, conduct data-driven farm operations, and integrate into digital supply chains. In Sukorambi and Wuluhan, field observations showed young farmers installing automated fertigation controllers based on microcontrollers, calibrating capacitive soil moisture probes, and analysing diurnal electrical conductivity (EC) values directly from mobile interfaces. Also, groups saw commercial advantages in working around intermediaries and recording harvest metrics in shared spreadsheets to feed directly to contracted DUDI partners in agribusiness. (3) Transformation (Reconfiguring Routines and System Maintenance): The young farmers radically transformed the traditional farming routines into accurate, digitally tracked agronomic systems and developed independent hardware maintenance capabilities. Observational logs and documentary evidence recorded a total shift from manual guesswork and hand written logs to automated smart phone irrigation timers and cloud hosted cultivation databases. Importantly, when system anomalies occurred, such as solenoid valve signal drops or telemetry errors, farmers exhibited transformative troubleshooting practices: instead of disengaging from the technology, they created real-time diagnostic circles with village champions to recalibrate boards and restore system operations.

The empirical expression of sense, seize and transform shows that the CAE model is not confined to the traditional hardware distribution. Non-formal education cultivates such dynamic capabilities through reciprocal partnership scaffolding, empowering adult learners to identify technological opportunities, leverage digital agricultural resources, and persistently re-configure farming operations in response to swift industry disruptions, thus supporting the theoretical proposition (OECD., 2023).

Moreover, the CAE framework establishes a continuous mentoring mechanism to address the severe problem of post-training skill decay directly in the view of lifelong learning and reciprocal governance . The framework conceptualises adult education as a continuous socio-technical process situated in rural communities, rather than an episodic event that ends with course completion. The CAE model formalises peer-to-peer problem solving and collective knowledge sharing by embedding local millennial farmer leaders as digital champions in village-level learning hubs. Instead of shutting down under the pressure of technological disruptions, young farmers tap into existing social capital and structures of communal learning for collective troubleshooting of technical errors. This community-based approach corresponds to the findings of Hilmi et al. (2023) on the effectiveness of local support systems for sustainable rural empowerment. It suggests that sustained agrotechnology adoption is dependent on institutionalizing continuous peer-led dynamic capability enhancement rather than periodic training workshops.

The practical implications of this study are directly actionable for managers of vocational education, policy makers and industry stakeholders. This research provides a concrete operational blueprint of restructuring of vocational curricula through joint steering committees with industry partners for the managers of Balai Latihan Kerja (BLK) and private training providers (LKP). The findings are a clear indication to local governments, particularly the Agricultural and Manpower Offices, that budget lines should be set aside for post-training mentorship networks and not just short-term training events. The proposed framework can serve as the foundation for the formulation of partnership standard operating procedures (SOPs) that can drive the digital transformation of rural youths, foster retention of young talents in the agrifood sector, and support regional food security initiatives, rather than claim the transformation.

This study, however, has limitations despite its comprehensive insight. The qualitative case study design was specifically focused on the agrarian hinterland of Jember Regency with its unique industrial characteristics. Therefore, the empirical results may be the result of local structural features different from those of non-industrial agricultural regions. Future research

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should utilise multi-case study designs across different geographical ecosystems and employ quantitative structural equation modelling (SEM) to measure the exact impact of the CAE model on farm productivity, income growth and long-term technology adoption rates among young farmers.

CONCLUSION

The study concludes that reciprocal partnerships between non-formal education institutions (such as BLKs) and the Business and Industrial World (DUDI) can be a mechanism to overcome structural disconnects in vocational agricultural training for young farmers. The rebuilt Continuing Agrotechnology Education (CAE) framework makes industry a co-architect of the curriculum and suggests a coherent pathway to integrate smart farming, IoT applications and data-driven cultivation into non-formal education systems. The primary theoretical contribution is to extend the understanding of non-formal education management from provider-centered management to the multi-stakeholder reciprocal governance, demonstrating how adult learning principles and dynamic capability building can be scaffolded in a joint manner in rural industrial environments. Practically, the framework points to the usefulness of digital learning hubs at the village level and youth-led peer mentoring networks to reduce skill decay after training. On the policy side, local government and vocational institutions are recommended to apply the reciprocal model in the formation of SOPs for agrotechnology empowerment programs. This study being qualitative and exploratory, suggests that future research should test the empirical validity and implementation of the proposed CAE model using multi-case comparative designs across different agro-ecological zones and employ quantitative structural equation modelling (SEM) to measure the longitudinal impact of the proposed CAE model on farm productivity, economic returns, and technology retention among young farmers.

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