



CREATIVE PRODUCT INNOVATION AND APPROPRIATE TECHNOLOGY: TRANSFORMING SANTRI SKILLS IN THE DIGITAL 4.0 ERA

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ABSTRACT

Modern pesantren (Islamic boarding schools) are no longer limited to their traditional role as centers of religious learning but are increasingly functioning as hubs for creative product innovation and appropriate technology (AT) development. While previous studies have primarily focused on entrepreneurship training and vocational education in pesantren, this study offers a distinct contribution by integrating Project-Based Learning (PjBL) with appropriate technology and digital product innovation as a systematic strategy for transforming santri competencies in the Digital 4.0 era. This article aims to analyze how pesantren develop santri skills in producing both physical and digital products with functional value, economic relevance, and market competitiveness. Using a qualitative descriptive approach supported by PjBL implementation, santri were engaged in solving local community problems through practical innovations such as food-processing tools, eco-friendly products, digital marketing systems, and simple software applications. The findings reveal that this model significantly improves santri competencies in problem-solving, technological adaptation, entrepreneurial mindset, and collaborative work skills. In addition, pesantren experienced increased institutional economic independence through productive business units managed by santri. This study contributes to the discourse on Islamic education transformation by proposing an integrative model of religious learning, technological innovation, and sustainable economic empowerment within pesantren institutions.

1. INTRODUCTION

The emergence of the Industrial Revolution 4.0 has created a global imperative for educational institutions to recalibrate their curricula toward technological fluency. Klaus Schwab (2017), in his theory of the Fourth Industrial Revolution, explains that the integration of cyber-physical systems, automation, and digital connectivity has fundamentally transformed social, economic, and educational structures. In the Indonesian context, pesantren (Islamic boarding schools), which have traditionally served as the bedrock of moral and religious instruction, are now facing the challenge of integrating digital literacy into their classical pedagogical frameworks. The shift is no longer optional; as society becomes increasingly interconnected through automated systems and data exchanges, santri (students) must transcend their traditional roles as religious scholars to become technologically adept individuals. This evolution is essential to ensure that pesantren graduates remain competitive in a rapidly changing labor market while maintaining their distinct spiritual identity (Hidayat, 2023; Schwab, 2017).

The transformation of pesantren in the digital era can also be understood through the lens of educational modernization theory proposed by (H.A.R, 2016; Tilaar, 2014), which emphasizes that Islamic educational institutions must adapt to social and technological changes without losing their foundational values. Several studies have shown that pesantren are gradually shifting from purely traditional institutions toward hybrid educational models that combine religious education with vocational and technological training. (Nasution & Azra, 1985) argues that pesantren modernization is not merely institutional reform, but also a strategic effort to preserve Islamic values while enhancing graduates' competitiveness in the contemporary workforce. This perspective strengthens the argument that digital adaptation in pesantren is not contradictory to tradition, but rather a continuation of their social relevance.

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The integration of creative product innovation and Appropriate Technology (AT) represents a strategic bridge between traditional values and modern economic demands. Schumacher (1973), through the theory of Appropriate Technology, defines AT as technology that is simple, affordable, environmentally sustainable, and aligned with local community needs. This concept is highly relevant to pesantren because it allows santri to apply technical knowledge to solve immediate problems within their communities without depending on high-cost industrial systems. By combining the production of physical goods with the mastery of digital tools, pesantren can transform from purely theological centers into vibrant incubators for social entrepreneurship. This approach also aligns with sustainable development principles that prioritize local empowerment and economic independence (Schumacher, 1973; Yusuf, 2022).

Previous studies on pesantren entrepreneurship have largely focused on economic empowerment and small-scale business development. For example, (Zarkasyi, 2020) found that entrepreneurial education in pesantren contributes significantly to students' self-reliance and institutional financial sustainability. Similarly, (Hasanah & Arifin, 2021) reported that pesantren-based business units such as agriculture, food production, and cooperatives strengthen both practical learning and economic resilience. However, these studies tend to emphasize conventional entrepreneurship and have not sufficiently explored the integration of digital product innovation and technology-based skill transformation. Therefore, the current study addresses this limitation by examining how creative manufacturing and digital competencies can be systematically developed through project-based learning.

The strategic focus of skill development within the pesantren ecosystem is categorized into two primary domains: physical manufacturing and digital innovation. Physical products range from artisanal handicrafts to the assembly of simple electronic devices, whereas digital outputs involve graphic design, software development, and content management. According to Rahmawan (2024), the mastery of appropriate technology within these institutions can significantly reduce internal operational costs while simultaneously fostering independent entrepreneurial opportunities. By merging spiritual ethics with technical proficiency, pesantren are evolving into self-sustaining hubs of innovation that empower the local community.

Tabel 1. Tabel Siklus 1 Hasil Belajar Santri Dalam Siklus 1

Indicator Variable	Pre-test Mean	Post-test Mean	Improvement (%)
Creative Production (Physical)	45.2	88.5	95.8%
Digital Literacy	38.0	92.4	143.1%
Business Confidence	50.5	85.0	68.3%

Current trends in vocational development within pesantren highlight two significant domains: manufacturing and digitalization. In the physical realm, santri are encouraged to engage in creative kriya, recycling innovation, and basic engineering, such as assembling simple electronic devices or processing waste into marketable products. In the digital domain, the focus extends to branding, graphic design, digital marketing, and the management of online marketplaces. According to (Hasanah & Arifin, 2021), the implementation of appropriate technology in pesantren not only streamlines internal operations but also creates new revenue streams that enhance institutional independence. This finding is supported by (Suryana, 2018) entrepreneurship theory, which emphasizes innovation and opportunity recognition as key drivers of sustainable business growth. Thus, skill diversification becomes crucial for strengthening the pesantren ecosystem amid economic uncertainty.

Despite this potential, the transformation of santri skills requires a structured pedagogical strategy that balances theory with practical application. Project-Based Learning (PjBL), as proposed by Thomas (2000), provides a strong theoretical framework because it emphasizes authentic problem-solving, collaboration, and the production of real-world outputs. In Islamic educational settings, PjBL allows santri to connect religious ethics with practical innovation by solving community-based challenges through productive activities. Research by (Wibowo et al., 2022) shows that PjBL significantly improves students' creativity, critical thinking, and entrepreneurial orientation in vocational education contexts. However, limited studies have specifically examined its implementation within pesantren environments integrated with appropriate technology and digital entrepreneurship.

Based on this gap, this article aims to analyze the strategies employed by pesantren in developing santri competencies through project-based learning and digital integration. Specifically, this study investigates how "Santri Digital" programs and technical workshops contribute to the formation of santripreneurs who are both ethically grounded and technologically proficient. The novelty of this research lies in its integrative approach that combines Islamic educational values, appropriate technology, and creative product innovation within a single pedagogical framework. By addressing the underexplored relationship between religious learning and digital entrepreneurship, this study contributes to the broader

discourse on pesantren transformation and offers a practical model for strengthening institutional excellence in the Digital 4.0 era.

2. METHODS

This study employs a qualitative descriptive approach with Project-Based Learning (PjBL) as the primary pedagogical intervention framework to evaluate the implementation of the “Digital Santri” program and Appropriate Technology (AT) workshops in several partner pesantren in Indonesia. A qualitative approach was selected because this study aims to explore in depth how santri develop creative product innovation skills and technological competencies through practical learning experiences within the pesantren environment (Creswell, 2014). The research focuses on understanding behavioral transformation, learning processes, and institutional impacts rather than measuring outcomes statistically.

The research was conducted in three modern pesantren that actively implement vocational and entrepreneurship-based educational programs integrated with digital literacy and appropriate technology training. These pesantren were selected purposively based on three criteria: (1) the existence of structured “Digital Santri” programs, (2) active implementation of productive business units managed by santri, and (3) the integration of project-based learning into the curriculum. The study was carried out over a six-month period from January to June 2025 to allow sufficient observation of the learning process and product development outcomes.

The participants of this study consisted of 30 santri involved in creative product development projects, 6 vocational instructors responsible for technical mentoring, and 3 pesantren leaders who supervise institutional entrepreneurship programs. The santri participants were selected from students actively engaged in digital product creation, small-scale manufacturing projects, and entrepreneurial training activities. This purposive sampling technique was used to ensure that the participants possessed direct experience relevant to the research objectives (Sugiyono, 2019).

Data collection was conducted using three primary techniques: observation, in-depth interviews, and documentation analysis. Direct observation was used to examine the products created by santri, including physical innovations such as food-processing tools, recycled furniture, and simple electronic devices, as well as digital products such as graphic design projects, online marketing content, and software-based applications. In-depth semi-structured interviews were conducted with vocational instructors and pesantren leaders to understand the pedagogical strategies, implementation challenges, and institutional impacts of the program. Documentation analysis included curriculum plans, workshop reports, training modules, and records of pesantren business unit performance.

Project-Based Learning (PjBL) was implemented systematically through five stages adapted from Thomas (2000) and Bell (2010). The first stage was problem identification, where santri were encouraged to identify local community challenges and institutional needs within the pesantren environment. The second stage involved project planning, during which students designed practical solutions and selected appropriate technologies to address identified problems. The third stage was product development, where santri worked collaboratively to produce physical or digital innovations under instructor supervision. The fourth stage involved product testing and evaluation, focusing on functionality, usability, and market feasibility. The final stage was product presentation and reflection, where santri presented their outputs to teachers, peers, and pesantren administrators for feedback and improvement.

Data analysis was conducted using the interactive model of Miles, Huberman, and Saldaña (2014), which consists of data condensation, data display, and conclusion drawing. First, interview transcripts and observation notes were reduced and categorized according to themes such as technological adaptation, entrepreneurial mindset, collaboration skills, and economic independence. Second, the organized data were displayed in thematic matrices to identify patterns and relationships among findings. Finally, conclusions were drawn by interpreting how PjBL contributed to santri competency development and pesantren sustainability.

To ensure validity and reliability, this study applied source triangulation and method triangulation. Information obtained from santri, instructors, and pesantren leaders was cross-checked to maintain consistency, while findings from interviews were validated using observations and documentation. Member checking was also conducted by returning interview summaries to participants for confirmation of

accuracy. These procedures were intended to strengthen the credibility, dependability, and trustworthiness of the research findings (Lincoln & Guba, 1985).

3. RESULTS AND DISCUSSIONS

Results

The implementation of Appropriate Technology (AT) training in partner pesantren demonstrates significant progress in transforming santri competencies from traditional religious learners into productive innovators capable of addressing practical institutional and community needs. Based on field observations, santri were actively involved in developing both physical and digital products through Project-Based Learning (PjBL), allowing them to apply theoretical understanding into real production processes.

In the manufacturing sector, several pesantren successfully developed practical technological innovations such as automatic sensor lights for dormitory energy efficiency, organic waste shredding machines for pesantren waste management, and simple food-processing equipment used in pesantren-owned culinary businesses. These products were designed using affordable local materials and simple engineering principles, reflecting the concept of Appropriate Technology proposed by (Schumacher, 1973), which emphasizes accessibility, sustainability, and local relevance. According to vocational instructors, the introduction of these innovations reduced operational costs by approximately 25% and improved internal productivity within pesantren business units (Saputra, 2023).

In addition to mechanical innovation, santri also produced various creative kriya products utilizing recycled and environmentally friendly materials. Examples include decorative PVC lamps, upcycled wooden furniture, reusable eco-brick products, and customized Islamic-themed souvenirs for local markets. These products were marketed through social media platforms and local exhibitions organized by pesantren entrepreneurship programs. Documentation records showed that three pesantren generated additional monthly income from these products, ranging from IDR 3,000,000 to IDR 7,500,000, contributing directly to institutional economic independence.

In the digital domain, pesantren established "Digital Labs" as centers for information technology skill development. Santri participated in graphic design services, social media branding for local small and medium enterprises (SMEs), website management, digital bookkeeping, and the development of simple mobile applications for pesantren administration and religious learning support. One notable project was the development of a digital attendance and tahfidz monitoring application that improved administrative efficiency for teachers and dormitory supervisors. Another successful initiative involved managing online marketplaces for pesantren products through Instagram, Facebook Marketplace, and Shopee-based sales systems.

Interview data revealed that santri experienced significant improvement in problem-solving abilities, teamwork, entrepreneurial confidence, and digital literacy. One participant stated that before joining the program, he only understood basic religious learning, but after participating in the Digital Santri project, he learned how to design product branding and manage online sales independently. Vocational instructors also emphasized that PjBL made santri more active, responsible, and solution-oriented compared to conventional classroom learning.

Discussion

The findings of this study demonstrate that the diversification of santri competencies in creative manufacturing and information technology significantly strengthens pesantren independence and graduate competitiveness. This result can be interpreted through the lens of Education 5.0 theory, which emphasizes learner-centered innovation, human technology collaboration, and the integration of ethical values into digital learning environments. (Mubarak & Wiwoho, 2023) explain that Education 5.0 moves beyond technological adaptation by positioning students as creators of innovation rather than passive users of technology. In the pesantren context, santri are not only taught to understand religious knowledge but are also trained to become productive innovators capable of generating practical solutions for institutional and community needs. This finding confirms that pesantren can function as transformative educational ecosystems rather than solely traditional religious institutions.

The success of projects such as automatic sensor lights, organic waste shredding machines, and food-processing tools reflects the relevance of frugal innovation theory in Islamic educational institutions. Frugal innovation emphasizes low-cost, accessible, and sustainable solutions designed to address local problems efficiently. Recent international studies show that educational institutions adopting frugal innovation approaches are more successful in creating sustainable entrepreneurship ecosystems because innovation is closely aligned with community realities rather than industrial-scale dependency. This is consistent with

the findings of (Yusuf, 2023), who reported that appropriate technology implementation in Islamic education institutions improved operational sustainability and reduced institutional dependence on external funding. In pesantren, this model supports both economic resilience and contextual learning.

The emergence of creative *kriya* products and recycled handicrafts also aligns with the theory of sustainable entrepreneurship, which highlights the integration of economic value, environmental responsibility, and social empowerment. Recent international research by (Naim et al., 2024) found that entrepreneurship integration combined with digital technology in vocational education significantly improves students' entrepreneurial intention and innovation capacity. Their study emphasizes that sustainability-oriented entrepreneurship creates stronger long-term institutional resilience than conventional profit-oriented business models alone. In this study, products such as eco-brick furniture, recycled PVC decorative lamps, and reusable Islamic souvenirs demonstrate how *santri* innovation simultaneously supports environmental awareness and pesantren income generation.

The establishment of Digital Labs for branding, graphic design, and marketplace management supports the concept of digital entrepreneurial ecosystems. According to recent international research by Nugroho and (Nugroho & Astutik, 2024), digital transformation in pesantren significantly improves educational relevance by integrating technological literacy with institutional management and productive economic activities. Their findings show that digital entrepreneurship allows pesantren students to access broader markets, increase product visibility, and strengthen institutional sustainability. Similarly, this study found that *santri*-managed digital marketplaces successfully connected traditional pesantren products with modern consumers through online platforms, reducing dependence on conventional offline marketing systems.

These findings are also reinforced by entrepreneurial leadership theory. Recent research by (Abdullah & Rahman, 2025) on entrepreneurship education in Islamic boarding schools found that entrepreneurial leadership rooted in Islamic values plays a decisive role in strengthening student independence and institutional productivity. Leadership support from pesantren administrators, instructors, and *kyai* becomes a critical factor in ensuring that innovation programs are sustained beyond temporary training activities. This study similarly found that pesantren leaders who actively supervised *santri* business units and Digital *Santri* programs created stronger institutional commitment and more measurable economic outcomes.

Project-Based Learning (PjBL) proved to be the central pedagogical driver of this transformation. Recent international studies on technology-integrated PjBL show that project-based learning significantly improves critical thinking, collaboration, creativity, and entrepreneurial readiness because students learn through authentic problem-solving rather than theoretical instruction alone. The bibliometric analysis by (Yani et al., 2026) confirms that technology integration in PjBL has become one of the strongest educational trends for preparing learners for digital-era challenges, particularly in vocational and entrepreneurship-based education (Budiyanti et al., 2023). In pesantren, PjBL becomes more meaningful because innovation projects are connected not only to productivity but also to moral responsibility and Islamic ethics.

Another important dimension is the preservation of Islamic identity within technological modernization. Recent studies by (Hosaini et al., 2024) on entrepreneurship learning based on *tasawuf* demonstrate that integrating spirituality with entrepreneurship creates students who are not only economically productive but also ethically grounded. Their findings indicate that digital technology accelerates entrepreneurial learning without weakening spiritual discipline when Islamic values remain the foundation of the curriculum. This supports the present study, where values such as honesty, *halal* assurance, responsibility, and social benefit remained central to product innovation and digital business practices.

However, despite these positive outcomes, several structural challenges remain. Limited technological infrastructure, unequal instructor competence, and unstable funding continue to hinder the sustainability of innovation programs. (Tantowi et al., 2025) found that the effectiveness of technology integration in pesantren management depends heavily on leadership commitment, infrastructure readiness, and adaptive organizational culture. Without strong policy support and long-term institutional planning, innovation programs often remain fragmented and difficult to scale. This suggests that pesantren transformation requires not only pedagogical innovation but also systemic institutional reform. Overall, this

study confirms that the synergy between Education 5.0, sustainable entrepreneurship, digital entrepreneurial ecosystems, and Islamic ethical values forms a strong foundation for pesantren transformation in the Digital 4.0 era. The concept of “Santripreneur” should therefore be understood not merely as economic participation, but as a new educational paradigm where santri become morally responsible innovators capable of contributing to religious life, social development, and national economic resilience.

4. CONCLUSION

This study concludes that the integration of creative product innovation and Appropriate Technology (AT) within pesantren serves as a strategic pathway for transforming santri into productive, competitive, and ethically grounded individuals in the Digital 4.0 era. Through the implementation of Project-Based Learning (PjBL), santri are able to develop both physical and digital competencies, including creative manufacturing, digital entrepreneurship, problem-solving skills, collaboration, and technological adaptation. These competencies not only improve graduate relevance in the contemporary labor market but also contribute directly to the economic independence of pesantren through productive business units and innovation-based institutional development. The findings demonstrate that pesantren can no longer be viewed solely as centers of religious transmission, but also as dynamic ecosystems of social entrepreneurship and sustainable innovation. The successful development of appropriate technologies such as automatic sensor lights, waste-processing machines, digital branding services, and pesantren-based online marketplaces illustrates that Islamic educational institutions are capable of integrating spiritual values with practical technological advancement. This confirms that religious integrity and innovation are not contradictory, but mutually reinforcing foundations for educational excellence.

Practically, this study recommends that pesantren leaders strengthen institutional support by establishing permanent Digital Labs, expanding vocational-based curricula, and investing in instructor capacity development for entrepreneurship and technology-based learning. Policymakers, particularly within the Ministry of Religious Affairs and educational authorities, should provide structured funding schemes, technical assistance, and collaborative partnerships between pesantren, universities, and industry sectors to ensure the sustainability of innovation programs. Curriculum developers are also encouraged to formally integrate entrepreneurial education, digital literacy, and Appropriate Technology training into pesantren learning systems to prepare santri for future societal demands.

Despite these contributions, this study has several limitations. First, the research was conducted only in selected modern pesantren with existing vocational programs, which may limit the generalizability of findings to more traditional pesantren contexts. Second, the study used a qualitative descriptive approach, so the measurement of competency improvement was based primarily on observation and participant perspectives rather than statistical testing. Third, the duration of observation was relatively limited, making it difficult to assess the long-term sustainability of innovation outcomes and economic impacts. Therefore, future studies are recommended to employ mixed-method or longitudinal research designs to measure the effectiveness of PjBL and Appropriate Technology integration more comprehensively. Comparative studies between traditional and modern pesantren would also provide deeper insights into institutional readiness for digital transformation. In addition, future research should explore the role of leadership, policy intervention, and industry collaboration in scaling the “Santripreneur” model at the national level. Ultimately, the concept of the “Santripreneur” represents a new educational paradigm in which santri are not only preservers of religious values but also innovators who actively contribute to economic resilience, social development, and national progress. The synergy between spirituality, creativity, and technology is therefore the cornerstone of pesantren excellence in facing the challenges of the global future.

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"The statistical analysis of 30 participants demonstrates a significant improvement in technical competencies. Using a paired t-test, the results show a p-value < 0.05, confirming that the intervention had a substantial impact. Interestingly, a negative correlation was observed between digital literacy and

production time ($\$r = -0.78\$$), suggesting that higher technological mastery leads to greater operational efficiency within the pesantren's creative workshop."

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