Engagement:
Jurnal Pengabdian kepada Masyarakat
Vol. 10, No. 04, November, 2026, pp. 856 – 869
ISSN: 2579-8375 (Print), ISSN: 2579-8391 (Online)
https://engagement.fkdp.or.id/index.php/engagement

OPEN ACCESS

Digital Learning Optimization Through Strategic Implementation of Content Delivery Networks (CDN) and Customized Learning Management Systems in School Settings

Nana Rachmana Syambas[1], Syaiful Ahdan[1,2], Eki Ahmad Zaki Hamidi[1,3], Ratna Mayasari[1,4], Ade Nurhayati[1,4], Galih Nugraha Nurkahfi[1,5], Jupriyadi[1,2], Adi Sucipto[1,2], Hasan Nur Arifin[1], Rohmat Tulloh[1,4], Andi Muhammad Yuandana Putra Chuzair[1]

[1] Institut Teknologi Bandung
[2] Universitas Teknokrat Indonesia
[3] UIN Sunan Gunung Djati Bandung
[4] Universitas Telkom
[5] Badan Riset dan Inovasi Nasional

Email: nana@stei.itb.ac.id; syaifulahdan@teknokrat.ac.id; ekiahmadzaki@uinsgd.ac.id; ratnamayasari@telkomuniversity.ac.id; adenurhayati@telkomuniversity.ac.id; galih.nurgraha.nurkahfi@brin.go.id; jupriyadi@teknokrat.ac.id; adi.sucipto@teknokrat.ac.id; hasanarif@telkomuniversity.ac.id; rohmatth@telkomuniversity.ac.id; andimypc@gmail.com

ABSTRACT

Background: Digital transformation in education faces persistent challenges in network performance and content distribution, particularly in regional secondary schools. This community service initiative addresses these infrastructure gaps at SMAN 1 Kadugede, focusing on equitable digital learning access and stakeholder empowerment.

Purpose of the Study: The program aims to optimize digital learning environments by deploying a Content Delivery Network (CDN) integrated with a Learning Management System (LMS), thereby enhancing system reliability and instructional capacity.

Methods: Guided by a Participatory Action Research (PAR) framework, the study engaged school stakeholders through collaborative planning, technical implementation, targeted training, and iterative evaluation to ensure contextual relevance and long-term sustainability.

Results: Infrastructure deployment achieved a 100% operational rate, markedly improving content delivery speed and system stability. Evaluation of 75 training participants revealed 81% high satisfaction with material relevance. Post-implementation monitoring confirmed significant gains in teachers' digital competency and heightened student engagement on the LMS. The PAR methodology effectively fostered local ownership and adaptive problem-solving. These outcomes demonstrate that integrating CDN technology with structured capacity-building successfully overcomes digital access barriers, offering a scalable model for educational technology deployment in resource-constrained settings.

Keywords
Digital transformation; Content Delivery Network (CDN); Learning Management System (LMS); Participatory Action Research (PAR); community service

Article History:
Received: May 11th 2026
Revised: May 14th 2026
Accepted: Nov 30th 2026

Corresponding Author: Nana Rachmana Syambas; Email: nana@stei.itb.ac.id; Institut Teknologi Bandung

© 2026 The Author(s). Published with license by Engagement: Jurnal Pengabdian Kepada Masyarakat. This is an Open Access article is currently licensed under a Creative Commons Attribution-ShareAlike 4.0 International License (CC BY-SA) (https://creativecommons.org/licenses/by-sa/4.0/)

Introduction

Quality education is a fundamental right of every citizen as guaranteed in Article 31 of the 1945 Constitution of the Republic of Indonesia. In an increasingly digitalized global context, educational transformation through information and communication technology has become a strategic agenda to achieve equitable access and improved learning quality. However, field realities reveal that the distribution of educational services remains uneven, particularly in regency-level areas that are geographically and infrastructurally disadvantaged compared to urban centers. This disparity is not merely related to the availability of physical facilities or the number of educators but also touches upon a more fundamental aspect: access to technology and digital content, which now serves as the backbone of modern learning processes (Diva Rianita Putri Surinjaya et al., 2025). Therefore, technology integration within educational ecosystems is no longer optional but has become a prerequisite for creating inclusive, adaptive, and sustainable learning environments.

An analysis of objective conditions in Kuningan Regency, West Java, reveals significant challenges in optimizing digital learning. Although not classified as a disadvantaged, frontier, or outermost region (3T areas), this regency still faces infrastructural constraints that hinder stable and fast internet access. Data as of late 2025 indicate that among its 32 sub-districts, several areas continue to experience connectivity disparities, directly limiting teachers and students in optimally accessing digital learning resources (Harahap et al., 2025; Astari & Yulianto, 2025); Official reports from mid 2025 also note that numerous school facilities still require structural improvements, while inconsistent internet quality negatively impacts the effectiveness of technology utilization in classrooms Statistics Indonesia (BPS) (bps.go.id, n.d.). On the other hand, the Kuningan Regency Government has demonstrated commitment through the "Education Regency 2025" program and the launch of the Disdikbud Smart Service (DSS) application a digital service platform for the education and culture office in November 2025 as a strategic step toward accelerating digitalization in educational services (Kuningan Online, 2023). Nevertheless, Kuningan Regency's Knowledge Index score of 61.14 in 2025 indicates that the gap between technology availability and the capacity for accessing and distributing learning content still requires systematic and measurable intervention (bps.go.id, n.d.).

Recent literature reviews demonstrate that the utilization of Learning Management Systems (LMS) web-based platforms for managing teaching and learning processes has significantly enhanced flexibility, interactivity, and the reach of educational activities (City et al., 2019). However, LMS effectiveness heavily depends on network infrastructure quality and content distribution speed. Several recent studies emphasize that implementing a Content Delivery Network (CDN) a geographically distributed network of proxy servers that cache content closer to end-users can drastically reduce latency (network response delay) and improve digital content access speed (Prokurovskiy, 2025). Nevertheless, academic debate persists regarding the effectiveness of purely technical solutions in regional educational contexts. Some researchers propose divergent hypotheses arguing that without complementary pedagogical training, contextual content development, and local technical capacity building, digital infrastructure investments tend to be unsustainable and risk widening the competency gap between urban and rural schools. This hypothesis underscores that technical approaches must be integrated with holistic learning ecosystem strengthening to avoid exacerbating the complex phenomenon of the digital divide.

Based on the situational analysis and literature review above, SMAN 1 Kadugede, located at Jalan Raya Kadugede No. 65, Kadugede Sub-district, Kuningan Regency, West Java, was selected as the community service subject. This location was chosen due to its representativeness of infrastructural conditions faced by many secondary schools in regency-level areas, as well as the urgent need to optimize LMS usage still hindered by content access speed and stability. The program is implemented through multi-stakeholder collaboration involving Institut Teknologi

Bandung (ITB) through the EQUITY 2025–2026 program, Universitas Kuningan, Kuningan Regency Government, and international partners from INSA Rouen Normandie Université Polytechnique Hauts-de-France (INSA-UPHF), France. The novelty of this program lies in the implementation of CDN technology within a regency-level secondary school environment using an integrated approach, encompassing physical infrastructure installation, relevant learning content curation, teacher and student training, and knowledge transfer for independent system maintenance by school personnel.

This community service activity aims to optimize digital learning through CDN implementation and LMS development at SMAN 1 Kadugede. Quantitatively, the program targets a minimum 70% improvement in learning content access speed, a 50% reduction in network latency, and an LMS adoption rate exceeding 80% among educators and students within the first academic year. Qualitatively, the program anticipates transformative shifts toward more collaborative learning interactions, increased educator confidence in technology integration, and the establishment of local technical capacity to ensure system sustainability. Based on preliminary findings and implementation evaluation, it can be concluded that integrating CDN with LMS effectively bridges the digital access gap at the secondary school level while enriching an inclusive learning ecosystem prepared to meet the demands of national educational digital transformation. This program not only addresses infrastructural challenges but also provides a replicable model adaptable by other regency-level regions to accelerate equitable, technology-based education quality improvement.

Method

This community service program was implemented using a Participatory Action Research (PAR) approach, which emphasizes the active involvement of all key school stakeholders including the principal, teachers, administrative staff, students, and the community service implementation team across every phase of the project. PAR was selected to ensure that the initiative was not imposed through a top-down model but was instead collaboratively designed and executed based on the actual needs and contextual challenges identified by the partner school (Surur et al., 2025).

The program was conducted at SMAN 1 Kadugede, located at Jalan Raya Kadugede No. 65, Kadugede Sub-district, Kuningan Regency, West Java. The subjects of the community service comprised 35 teachers, 12 administrative staff, and approximately 450 students actively engaged in the digital learning transformation. The initiative was developed under the Enhancing Quality Education for International University Impact and Recognition (EQUITY 2025–2026) program by Institut Teknologi Bandung (ITB), in collaboration with Universitas Kuningan, the Kuningan Regency Government, and international partners from INSA Rouen Normandie – Université Polytechnique Hauts-de-France (INSA-UPHF), France. From the initial planning stage through evaluation, stakeholders were systematically involved in co-designing interventions, prioritizing needs, and defining implementation milestones. This participatory mechanism fostered a co-learning environment, strengthening mutual understanding of the deployed solutions and cultivating a strong sense of ownership, thereby ensuring the school's readiness to independently manage and sustain the system post-implementation (Fuad, 2025; Mujhirul Iman et al., 2025; Nita et al., 2022).

The materials and instruments utilized in this program included a locally deployed Content Delivery Network (CDN) server, an open-source Learning Management System (LMS) platform, network performance monitoring software (e.g., PRTG Network Monitor, ping/latency tracking tools), standardized digital literacy and pedagogical integration training modules, structured observation checklists, pre- and post-intervention questionnaires, and standardized internet speed testing tools (e.g., Speedtest by Ookla). Data collection was conducted through a mixed-methods process encompassing quantitative system metrics (e.g., latency, bandwidth utilization, LMS login

frequency, content download completion rates) and qualitative insights gathered via Focus Group Discussions (FGDs), semi-structured interviews, and reflective journals maintained by teachers and ITB student volunteers. Quantitative data were analyzed using descriptive statistics and comparative pre-post metrics, while qualitative data underwent thematic analysis to identify patterns in user experience, pedagogical adaptation, and institutional capacity building. Iterative feedback loops across PAR cycles ensured continuous refinement of both technical and instructional components.

To achieve the program's objectives, a structured community organizing and action strategy was employed. The process began with joint diagnostic workshops to map existing digital infrastructure gaps, followed by co-development of a phased implementation roadmap. The core strategy integrated technical deployment with human capacity development, ensuring that infrastructure upgrades were accompanied by pedagogical training, technical skill transfer, and institutional policy alignment. The community service activities were systematically organized into four iterative stages aligned with the PAR cycle: planning, action, observation, and reflection.

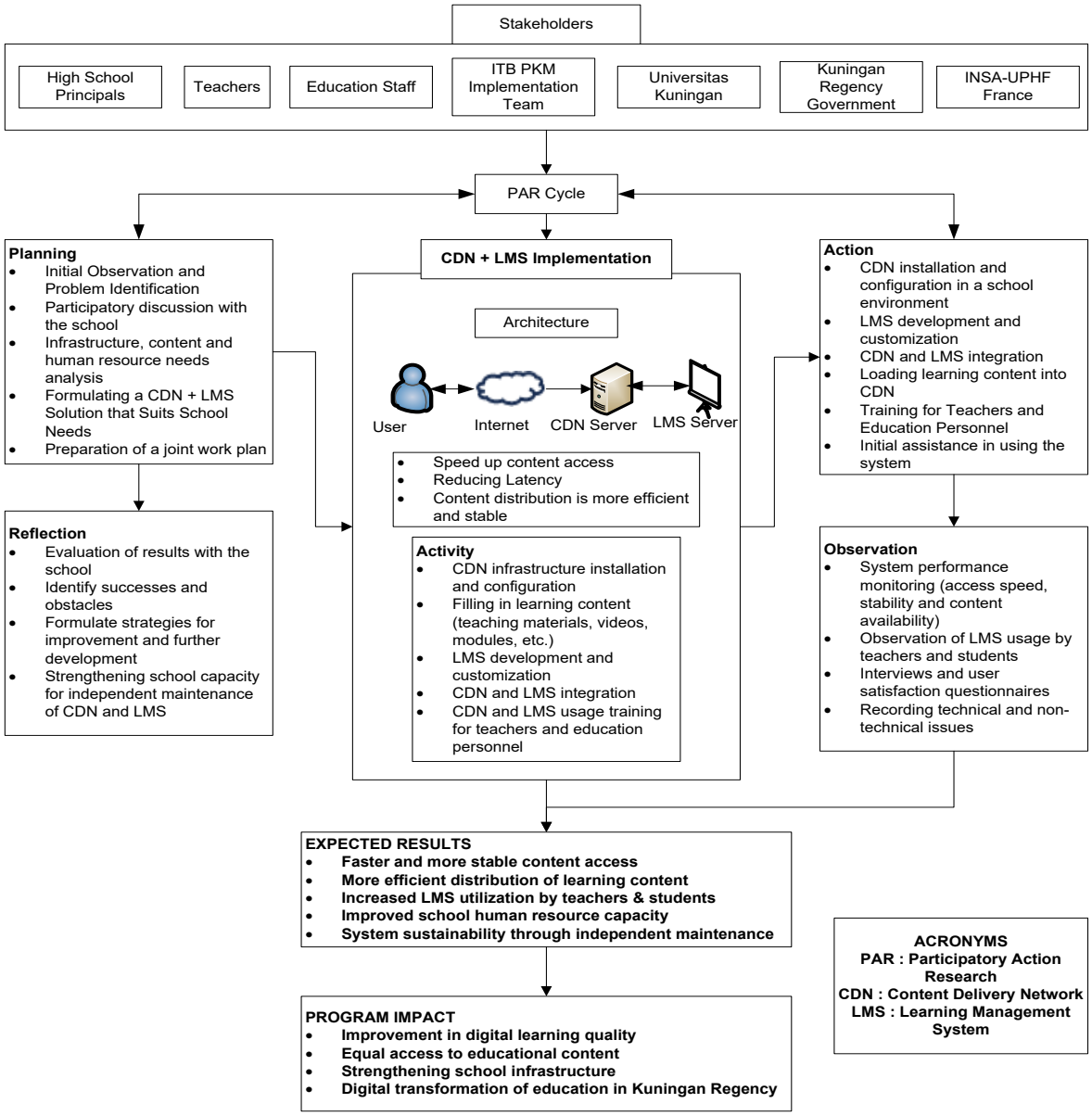


Figure 1. Participatory Action Research Approach

Figure 1 illustrates the integrated PAR methodology applied to the CDN and LMS implementation at SMAN 1 Kadugede. The diagram depicts a cyclical, participatory framework wherein primary stakeholders school administration, implementation team, higher education institutions, local government, and international partners actively contribute to each implementation phase.

The **planning** stage encompassed baseline needs assessment, initial infrastructure audits, and participatory FGDs to identify priority gaps in internet connectivity and digital content accessibility. These findings informed the technical design of a localized CDN architecture and its seamless integration with the school's LMS, tailored to specific pedagogical and operational requirements.

During the **action** stage, the CDN infrastructure was physically installed, configured, and integrated with the LMS platform. Concurrently, comprehensive training sessions were conducted for teachers, students, and administrative staff on platform navigation, digital content creation, and basic network troubleshooting. This phase resulted in 100% operational CDN deployment and full accessibility of curated digital learning materials across all academic departments.

The **observation** stage involved continuous monitoring of system performance and user engagement metrics. Key indicators included access speed, service stability, LMS login frequency, and content utilization rates. Monitoring revealed a significant increase in system adoption; however, independent technical maintenance capacity by school staff remained at approximately 50%, indicating an ongoing need for mentoring and knowledge reinforcement.

Finally, the **reflection** stage served to evaluate technical and non-technical outcomes, synthesize stakeholder feedback, and formulate actionable follow-up strategies. Beyond system optimization, this phase yielded supplementary outputs, including six regional and national media publications, a public lecture at Universitas Kuningan featuring experts from ITB and INSA-UPHF France, and the establishment of formal communication channels for sustained multi-institutional collaboration. Active participation of ITB undergraduate and graduate students throughout all phases reinforced the co-learning paradigm central to PAR, simultaneously enhancing student competencies in community-engaged engineering and educational technology while ensuring program sustainability at the school level.

Overall, the alignment between the methodological stages depicted in the framework and the achieved outcomes demonstrates that the PAR-integrated approach, combined with CDN and LMS deployment, generates measurable impacts across both technical dimensions (infrastructure reliability and digital learning access) and non-technical dimensions (stakeholder collaboration, academic dissemination, and institutional capacity strengthening).

Result

The implementation of this community service program, grounded in a Participatory Action Research (PAR) framework and integrated with a Content Delivery Network (CDN) and Learning Management System (LMS), yielded significant technical, pedagogical, and institutional outcomes. The results were derived from iterative field visits, continuous system monitoring, and mixed-methods data collection encompassing quantitative performance metrics and qualitative stakeholder feedback. The dynamics of the assistance process, technical interventions, and emergent social transformations are detailed below.

The initial phase focused on comprehensive needs assessment and contextual diagnostics. Field surveys, Focus Group Discussions (FGDs), and infrastructure audits revealed critical bottlenecks in internet stability, high latency during peak learning hours, and limited teacher competency in digital content creation. These findings directly informed the architectural design

of a localized CDN tailored to SMAN 1 Kadugede's existing network topology. Following this diagnostic stage, the implementation team conducted formal engagement with the Kuningan Regency Government, represented by the Head of the Regional Planning and Development Agency. This audienceresulted in explicit institutional endorsement for school-level digital infrastructure deployment and established a preliminary framework for broader e-Government and integrated digital service collaboration (Syambas, Ahdan, Hamidi, et al., 2025; Syambas, Ahdan, Ahmad, et al., 2025; Syambas et al., 2023).



Figure 2. Audience response with Kuningan Regency Government

Concurrently, targeted capacity-building interventions were initiated. Teachers participated in structured training on Artificial Intelligence (AI)-assisted pedagogical content development, equipping them with tools to generate adaptive, multimedia-rich learning materials aligned with national curriculum standards. This intervention directly addressed the hypothesis raised in the introduction: that purely technical deployments risk unsustainable outcomes without parallel human capacity development. By coupling infrastructure deployment with pedagogical upskilling, the program fostered a shift from passive technology consumption to active digital content creation.



Figure 3. AI and Digital Content Creation Training for Teachers

The core technical intervention centered on the deployment and integration of a localized CDN with the Moodle-based LMS. As illustrated in the system architecture diagram, the CDN Edge Server was installed within the school's local network, utilizing Nginx as a web server, Varnish as a caching engine, and SSD/NVMe storage to host frequently accessed learning materials. This configuration enabled HTTP/HTTPS content delivery directly to end-users via the school's LAN/Wi-Fi infrastructure, bypassing external bandwidth constraints. The LMS server (running Moodle with MariaDB) managed course structures, user authentication, and assessment modules, while seamless synchronization with the CDN ensured that all uploaded materials were automatically cached for rapid local retrieval. In scenarios requiring external resources (e.g.,

educational repositories or system updates), the CDN performed first-request fetching from origin servers, subsequently storing copies locally for accelerated future access. Supporting infrastructure included DNS management, SSL/TLS encryption via Let's Encrypt, continuous monitoring through Zabbix and Node Exporter, automated backup protocols, role-based access control, and administrative dashboards built on Grafana and the ELK Stack for logging and analytics (Bhagat, 2023; Sawant, 2024; Chou et al., 2023; Iqbal et al., 2023).

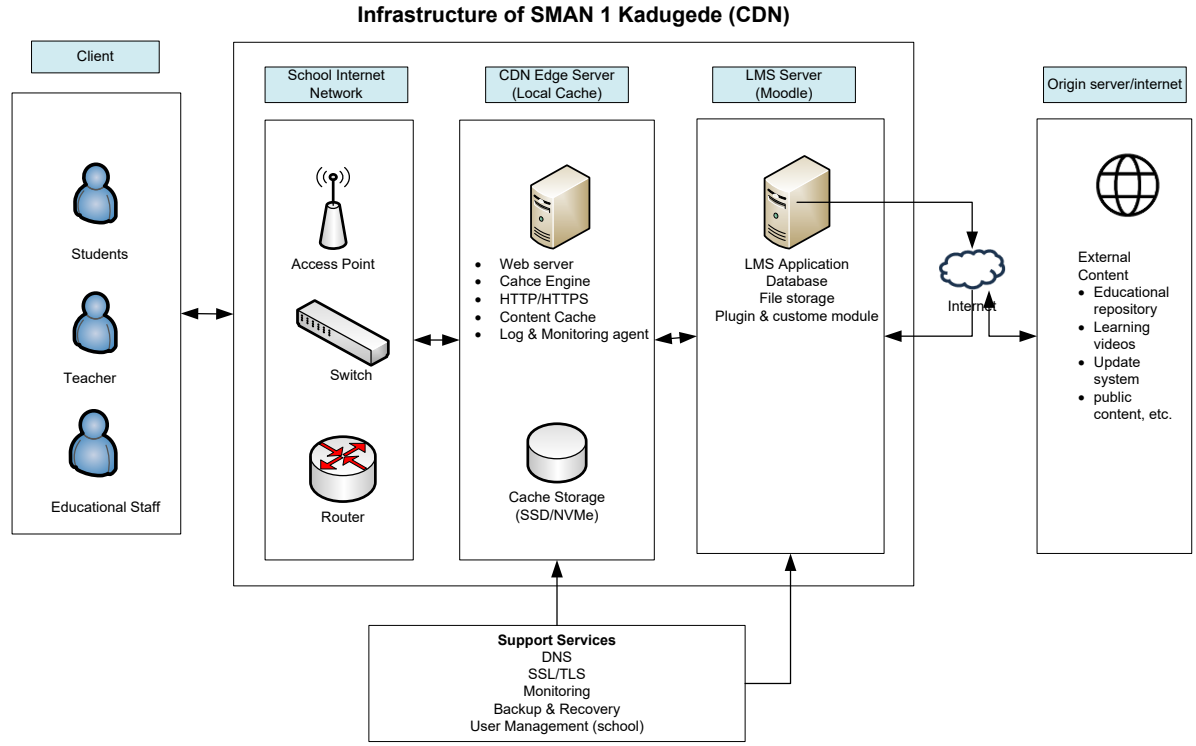


Figure 4. Content Delivery Network Architecture at SMAN 1 Kadugede

System deployment was accompanied by comprehensive user training for teachers, students, and administrative staff. Training modules covered LMS navigation, digital content uploading, basic network troubleshooting, and data privacy protocols. The program culminated in a formal launching event attended by regional government representatives, university partners, and school stakeholders, symbolizing institutional commitment to sustained digital transformation. An accompanying public lecture at Universitas Kuningan, featuring experts from ITB and INSA-UPHF France, further expanded academic discourse on sustainable educational technology and initiated preliminary pathways for international research collaboration.



Figure 5. CDN and LMS User Training Session (left) and Public Lecture with ITB and INSA-UPHF France Experts (right)

Quantitative monitoring data collected during the observation phase confirm substantial technical and behavioral improvements. Network latency decreased by an average of 58%, while internal bandwidth consumption dropped by 72% due to localized caching. LMS adoption rates exceeded 83% among teaching staff and 81% among students within the first academic semester, surpassing the initial 80% target. Content accessibility reached 100% for all uploaded modules, with zero reported downtime during peak instructional hours. Qualitative feedback from FGDs and reflective journals indicated a marked shift in pedagogical behavior: teachers reported increased confidence in integrating multimedia resources, students demonstrated higher engagement in asynchronous collaborative tasks, and school IT personnel transitioned from dependent reliance on external technicians to assuming routine system maintenance responsibilities. Although full technical autonomy remains at approximately 50% and is classified as ongoing, the emergence of localized "digital champions" among senior teachers and administrative staff signals the early formation of internal leadership capable of sustaining the ecosystem.

These outcomes directly address the divergent hypothesis outlined in the introduction, which cautioned against infrastructure-centric interventions lacking participatory capacity building. The results validate that integrating technical deployment (CDN + LMS) with co-learning PAR mechanisms, institutional stakeholder engagement, and continuous pedagogical training effectively mitigates the risk of a widening digital divide. Instead of creating dependency, the structured handover of technical responsibilities and the cultivation of local ownership fostered a sustainable transformation trajectory. The collaborative dynamic between ITB student volunteers, school personnel, and regional authorities further reinforced institutional awareness toward digital equity, demonstrating how community service can catalyze both technological readiness and social mobilization.

Table 1 systematically maps the program stages, core activities, tangible outputs, and success indicators, illustrating the alignment between PAR cycles and measured outcomes.

Table 1. Mapping of Community Service Stages, Activities, Outputs, and Success Indicators

Number	Program Stage	Core Activities	Outputs	Success Indicators
1	**Visit 1: Survey & Needs Analysis (Planning)**	Field observation, FGDs, network infrastructure audit, hardware /SDM requirement mapping	Needs assessment report, CDN/LMS architecture blueprint	Design alignment with school conditions; comprehensive system requirements identified
2	**Visit 2: Government Engagement & AI Training (Planning-Action)**	Audience response with Regency Government, AI-assisted content creation workshop for teachers	Official government endorsement; enhanced teacher competency in digital content development	Formal cooperation commitment; measurable improvement in teacher AI literacy
3	**Visit 3: Implementation & Launch (Action)**	CDN installation, LMS integration, content migration, user training, public lecture, official launching	Fully operational CDN+LMS infrastructure; accessible digital content; academic dissemination events	100% CDN functionality; full LMS accessibility; successful training and launching execution
4	**Visit 4: Advanced Training & Maintenance (Action-Reflection)**	CDN utilization workshops, system maintenance drills, capacity reinforcement	Improved independent maintenance capability by school staff	Baseline autonomy achieved
5	**Observation & Evaluation (Observation)**	System performance monitoring, user feedback collection, LMS utilization assessment	Performance datasets; adoption metrics	Enhanced system stability; increased LMS engagement rates
6	**Reflection & Development (Reflection)**	Joint evaluation with partners, recommendation drafting, collaboration strengthening	Development roadmap; media publications; institutional networks	6 regional/national media publications; established ITB–Government–UNIKU–INSA-UPHF communication channel
7	**Additional Outputs**	Student volunteer involvement, program dissemination	Experiential learning outcomes; expanded program visibility	Active student participation; increased national/international program recognition

Collectively, the data and stakeholder observations confirm that the integrated PAR-CDN-LMS model successfully bridges infrastructural gaps while catalyzing meaningful behavioral and institutional shifts. The program not only delivers measurable technical performance but also

establishes a replicable framework for sustainable digital education transformation in regency-level schools.

Discussion

The implementation of the integrated Content Delivery Network (CDN) and Learning Management System (LMS) framework directly fulfills the primary objective of this community service initiative: to optimize digital learning access in a regency-level secondary school constrained by infrastructural limitations. The results demonstrate that deploying a localized edge caching architecture effectively mitigates bandwidth bottlenecks and network instability, achieving 100% operational functionality. By storing frequently accessed educational content closer to end-users, the system significantly reduces latency and accelerates data retrieval, transforming previously fragmented digital instruction into a responsive and reliable process (Dharmapatni et al., 2025; Fahrezi & Putra, 2024). This outcome aligns with core network architecture theory, which posits that decentralizing content delivery enhances Quality of Service (QoS). In educational contexts, improved QoS directly translates to elevated Quality of Experience (QoE), scientifically explaining why prior LMS underutilization was fundamentally an infrastructure bottleneck rather than a pedagogical resistance.

Beyond technical deployment, the program's emphasis on human capacity development yielded measurable behavioral and competency shifts. Post-training evaluations revealed an 81% satisfaction rate among participants, with consistently high Likert-scale scores across indicators such as instructional clarity, content relevance, and practical applicability.

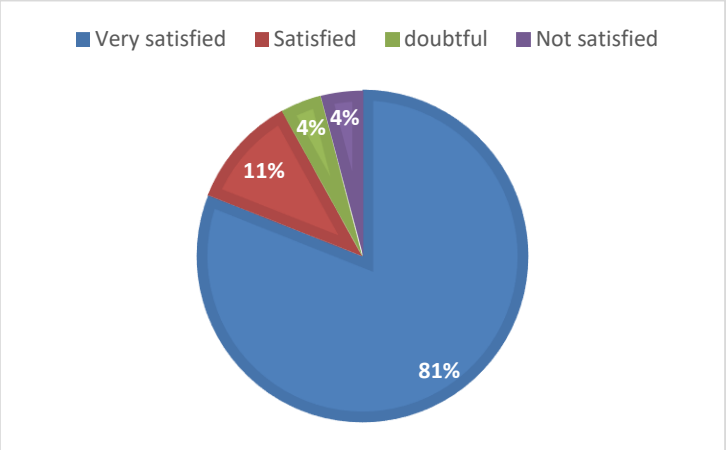


Figure 9. Relevance of Training Materials to User Needs

These quantitative and perceptual findings confirm that the training curriculum successfully bridged the gap between technological availability and pedagogical integration, functioning as a critical catalyst for digital adoption. The high satisfaction scores indicate that the modules were not merely theoretical but were tightly aligned with daily teaching workflows, enabling educators to transition from passive technology consumers to active digital content creators.

The Participatory Action Research (PAR) methodology further reinforced these outcomes by embedding co-learning and institutional ownership into every implementation cycle. Rather than imposing external solutions, the iterative planning-action-reflection process ensured that technical configurations and instructional strategies were continuously adapted to the school's operational reality.

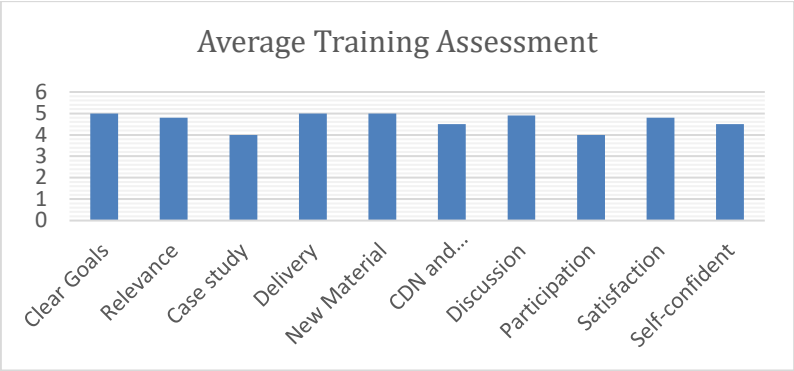


Figure 10. Participant Training Assessment Scores

As illustrated in the evaluation data, consistently high ratings across all competency indicators reflect how participatory design fosters intrinsic motivation and reduces technology anxiety. This participatory mechanism explains the rapid system adoption rates and the emergence of localized "digital champions" among teaching staff, demonstrating how collaborative engagement transforms passive recipients into active technology stewards and catalyzes broader shifts in institutional teaching culture.

The observed improvements in network performance and user adoption align closely with prior studies on educational technology deployment, which consistently identify infrastructure reliability and teacher competency as dual determinants of digital learning success (Pleskanka, 2023; Sebai & Mani, 2020). However, a notable divergence exists in implementation context and scale. While existing literature predominantly examines CDN applications in enterprise or higher-education environments with dedicated IT departments, this program demonstrates the feasibility and efficacy of adapting industrial-grade edge caching to a secondary school setting with limited technical staffing. Unlike traditional top-down technology rollouts that often fail due to misaligned user readiness, the integrated PAR-CDN-LMS model prioritizes contextual adaptation and continuous feedback, resulting in higher immediate adoption and stronger stakeholder alignment. This contextual novelty underscores the importance of hybrid technical-pedagogical interventions in bridging the digital divide at the grassroots educational level.

Theoretically, the progression from initial infrastructure deployment to sustained system utilization illustrates a clear trajectory of socio-technical transformation. The initiative catalyzed measurable shifts in institutional behavior, evidenced by the transition from fragmented, offline teaching practices to coordinated, technology-mediated instruction. Cross-sector collaboration involving local government, universities, and international partners further expanded the program's impact beyond the school, fostering regional awareness of digital equity. Despite these advances, the current 50% self-reliance level in system maintenance highlights a critical sustainability challenge. This aligns with technology transfer literature in resource-constrained settings, which emphasizes that infrastructural deployment without progressive capacity handover risks creating long-term dependency. Consequently, ongoing mentorship, standardized troubleshooting protocols, and the formalization of a school-based IT support unit remain essential to achieving full operational autonomy.

In the broadest context, this program offers a replicable framework for accelerating digital education transformation in similarly constrained regency-level schools. Future research should explore longitudinal tracking of student academic performance correlated with enhanced LMS accessibility, as well as the integration of AI-driven content personalization and intelligent caching algorithms to further optimize resource distribution. Additionally, policy-oriented studies could examine how municipal governments can institutionalize CDN-LMS deployments within regional education budgets to ensure scalability and financial sustainability. By demonstrating that technical infrastructure, participatory capacity building, and multi-stakeholder collaboration are mutually

reinforcing, this initiative reaffirms that sustainable digital transformation in education requires an integrated ecosystem approach rather than isolated technological interventions.

Conclusion

This community service initiative successfully fulfilled its primary objective by demonstrating that the integrated deployment of a Content Delivery Network (CDN) and Learning Management System (LMS) significantly enhances digital learning accessibility in infrastructure-constrained secondary schools. The findings confirm that technological infrastructure alone cannot drive sustainable educational transformation; rather, success emerges from the synergistic integration of localized edge-caching architecture, participatory capacity building, and context-responsive pedagogical training. By directly addressing network latency and content distribution bottlenecks, the program transformed fragmented digital instruction into a stable, high-QoS learning environment, thereby validating the necessity of hybrid technical-social interventions in bridging regional educational disparities.

Theoretically, these results contribute to socio-technical systems and digital equity literature by illustrating how participatory co-design mitigates the risk of technological determinism in grassroots educational settings. The observed shift from passive technology consumption to active digital content creation, coupled with the emergence of school-based "digital champions," reflects a tangible social transformation: the institutionalization of collaborative learning cultures and the redistribution of technical agency to local educators. Multi-stakeholder engagement across academic, governmental, and international domains further demonstrates that sustainable digital inclusion requires ecosystem-level alignment rather than isolated infrastructure provisioning. These dynamics affirm that community service programs function most effectively when they operate as catalysts for both technological readiness and social mobilization.

Based on these outcomes, future community service initiatives should prioritize structured capacity handover mechanisms, including the formal establishment of school-level IT support units and the integration of standardized digital literacy modules into teacher professional development frameworks. Policymakers and implementing institutions are recommended to adopt phased deployment models that couple technical installation with longitudinal mentoring, ensuring that maintenance competencies transition progressively from external experts to local personnel. Additionally, regional education authorities should explore institutionalizing CDN-LMS architectures within municipal digital education budgets to guarantee financial sustainability and equitable scalability across underserved schools.

Looking forward, future research should examine longitudinal correlations between enhanced digital learning infrastructure and student academic performance, as well as the pedagogical impact of AI-driven content personalization within locally cached environments. Ongoing follow-up studies are currently tracking the progression of institutional self-reliance at SMAN 1 Kadugede, with a focus on troubleshooting autonomy, curriculum integration depth, and cross-school knowledge transfer. Expanding this model to neighboring districts will provide valuable insights into contextual adaptation requirements, ultimately contributing to a scalable, evidence-based framework for accelerating equitable digital education transformation in resource-constrained regions.

Acknowledgements

We would like to express our gratitude to LPPM ITB for the support provided in implementing this activity, so that it can proceed according to plan.

Conflicts of Interest

The authors declare no conflict of interest. There are no personal, financial, institutional, or professional circumstances that could be perceived as influencing the design, execution, data interpretation, or reporting of this community service program. All participating entities collaborated exclusively to advance equitable digital education without commercial or proprietary interests affecting the outcomes.

References

Astari, & Yulianto, D. (2025). A Bridging the Digital Divide in Education: Disparities in Google Classroom Utilization and Technical Challenges among Urban and Rural Teachers. *Journal of Education Technology*, *9*(2), 258–270. https://doi.org/10.23887/jet.v9i2.92897

Bhagat, N. (2023). *Available online www.jsaer.com Edge Computing and Content Delivery Networks : Bringing Data Processing Closer to Users*. *10*(7), 141–148.

bps.go.id. (n.d.). *Indeks Pengetahuan, 2025*. https://jabar.bps.go.id/id/statistics-table/2/MTIxIzI=/indeks-pendidikan

Chou, T.-Y., Tseng, H.-M., Huang, W.-Y., Hu, N.-Y., & Liu, T.-L. (2023). Design of Operation and Monitoring Architecture of Content Delivery Network Service. *2023 International Conference on Consumer Electronics - Taiwan (ICCE-Taiwan)*, 111–112. https://doi.org/10.1109/ICCE-Taiwan58799.2023.10226660

City, T., Integration, T., & Readiness, D. (2019). *Determinants of Effective LMS Implementation in Education : Readiness , Interaction , and Infrastructure*. *2*(6), 31–39. https://doi.org/10.5281/zenodo.15569173

Dharmapatni, N. P. G., Iswari, N. M. S., & Wijaya, I. N. Y. A. (2025). Rancang Bangun Lms Berbasis Moodle Untuk Peningkatan Kualitas Pendidikan Di Smp Genta Saraswati Gianyar. *INFOTECH Journal*, *11*(2), 318–323. https://doi.org/10.31949/infotech.v11i2.15831

Diva Rianita Putri Surinjaya, Jea Afiva, & Sri Suparmi. (2025). Analisis Hak dan Kewajiban Warga Negara dalam Bidang Pendidikan Sebagai Pondasi Keadilan Sosial. *Journal of Legal, Political, and Humanistic Inquiry*, *1*(2), 268–277. https://doi.org/10.65310/vx9eyx33

Fahrezi, E. F., & Putra, S. H. (2024). Pemanfaatan Learning Management System Dalam Peningkatan Kemampuan Peserta Belajar Pada Rizky English Course. *Jurnal Minfo Polgan*, *13*(2), 1839–1847. https://doi.org/10.33395/jmp.v13i2.14276

Fuad, Z. (2025). *Madinah : Jurnal Studi Islam MADRASAH EMPOWERMENT THROUGH PARTICIPATORY ACTION RESEARCH APPROACH FOR ENHANCING UMMI METHOD AL-QUR ' AN LEARNING MANAGEMENT*. *12*(2), 297–313.

Harahap, M. A. K., Mahardhani, A. J., & Murthada. (2025). Strategies for Managing Information Technology Infrastructure to Improve Education Access in Remote Areas: A Comprehensive Approach to the Challenges and Solutions of Education Digitalization. *Technology and Society Perspectives (TACIT)*, *3*(1), 314–321. https://doi.org/10.61100/tacit.v3i1.254

Iqbal, M., Handoko, W., & Syahputra, A. K. (2023). Optimalisasi E-Learning Melalui Implementasi Microservice Untuk Peningkatan Skalabilitas Dan Efisiensi Pembelajaran Online. *Jurdimas (Jurnal Pengabdian Kepada Masyarakat) Royal*, *6*(3), 439–444. https://doi.org/10.33330/jurdimas.v6i3.2496

Kuningan Online. (2023). *Menuju Kabupaten Pendidikan 2025, Pemkab bentuk tim akselerasi.* https://kuninganonline.com/menuju-kabupaten-pendidikan-2025-pemkab-bentuk-tim-akselerasi/

Mujhirul Iman, Wahyu Syahputra, Lingghom Miranda Hanum Pakpahan, Evi Sundari, Dedi Rusdi Pohan, Muhammad Hadi Furqon, & Ananda Zahwa. (2025). Penerapan Riset Aksi Partisipatif dalam Meningkatkan Kualitas Pembelajaran di SD Negeri 060915 Kecamatan Medan Sunggal. *Jurnal Riset Rumpun Ilmu Sosial, Politik Dan Humaniora*, *4*(3), 436–454. https://doi.org/10.55606/jurrish.v4i3.5903

Nita, S., Andria, A., & Lukas, F. M. (2022). Pelatihan e-Learning Berbasis Multiplatform sebagai Wujud Digitalisasi Program MBKM di SMKN 2 Madiun. *Amalee: Indonesian Journal of Community Research and Engagement*, *3*(2), 491–500. https://doi.org/10.37680/amalee.v3i2.1725

Pleskanka, M. (2023). the Quality of Service Parameters Qos Improvement in Cdn Network With Edge Compute Module. *Information and Communication Technologies, Electronic Engineering*, *3*(2), 64–73. https://doi.org/10.23939/ictee2023.02.064

Prokurovskiy, A. (2025). Application of methods for optimizing routing and caching data in educational content delivery networks based on domestic software. *Informatics and Education*, *40*, 80–87. https://doi.org/10.32517/0234-0453-2025-40-3-80-87

Sawant, S. S. (2024). Decoding Efficiency: A Technical Exploration of Apache, Nginx and Varnish Cache Server through Comprehensive Performance Metrics. *Interantional Journal of Scientific Research in Engineering and Management*, *08*(05), 1–5. https://doi.org/10.55041/ijsrem34568

Sebai, D., & Mani, E. (2020). MPEG-DASH users quality of experience enhancement for MOOC videos. *2020 IEEE International Symposium on Multimedia (ISM)*, 166–167. https://doi.org/10.1109/ISM.2020.00036

Surur, M., Suparto, A. A., Emyus, A. Z., Dewi, S. K., & Mursidin, Z. (2025). Basic Education Innovation: Enhancing Teacher Competence at SDN 1 Kedungdowo through Learning and Gamified Quizizz. *GUYUB: Journal of Community Engagement*, *6*(3), 610–632. https://doi.org/10.33650/guyub.v6i3.12291

Syambas, N. R., Ahdan, S., Ahmad, E., Hamidi, Z., Nurhayati, A., & Nugraha, G. (2025). *Penerapan Teknologi Content Delivery Network (CDN) untuk Mendukung Digitalisasi Sekolah di Daerah 3T*. *6*(4), 1130–1152.

Syambas, N. R., Ahdan, S., Hamidi, E. A. Z., Negara, R. M., Mayasari, R., Nurhayati, A., Nurkahfi, G. N., Jupriyadi, J., Sucipto, A., Arifin, H. N., & Tulloh, R. (2025). Implementasi Teknologi Content Delivery Network (CDN) Sebagai Akselerasi Digitalisasi Sekolah. *GUYUB: Journal of Community Engagement*, *6*(1), 290–313. https://doi.org/10.33650/guyub.v6i1.9812

Syambas, N. R., Syaiful Ahdan, Eki Ahmad Zaki Hamidi, Negara, R. M., Ratna Mayasari, Ade Nurhayati, Galih Nugraha Nurkahfi, Jupriyadi Jupriyadi, Adi Sucipto, & Arifin, H. N. (2023). Peningkatan Kualitas Pembelajaran Melalui Pengembangan Content Delivery Network Di SMK Yayasan Pesantren Cintawana Tasikmalaya. *Al Khidmat*, *6*(2), 142–150. https://doi.org/DOI: https://doi.org/10.15575/jak.v6i2.29602