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A simple middleware framework for integrating audio-visual systems in small educational institutions

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Abstract
Audio-visual (AV) technologies have become essential components of contemporary teaching-learning environments, supporting interactive pedagogy, blended learning, and effective content delivery. However, small educational institutions often face persistent challenges in deploying and managing AV systems due to budget constraints, heterogeneous hardware, lack of technical expertise, and limited scalability. Existing commercial AV integration solutions are frequently expensive, complex, and designed for large-scale enterprises, making them unsuitable for smaller institutions. This research proposes a simple middleware framework aimed at integrating disparate audio-visual systems within small educational institutions in a cost-effective, flexible, and manageable manner. The proposed framework acts as an intermediary layer between AV hardware and user-facing applications, enabling seamless communication, centralized control, and standardized data exchange. The architecture is designed with modular components that support device discovery, protocol abstraction, media synchronization, and basic fault handling, while remaining lightweight and easy to deploy on commonly available computing infrastructure. Emphasis is placed on interoperability with heterogeneous devices such as projectors, microphones, speakers, cameras, and display systems, which are often procured incrementally over time. The framework prioritizes minimal configuration requirements and reduced dependency on proprietary software, allowing institutions to leverage open standards and existing network resources. Through conceptual validation and design analysis, the research demonstrates how the middleware approach can simplify AV system management, improve reliability, and enhance classroom usability without imposing significant financial or technical burdens. The proposed solution contributes to the ongoing discourse on educational technology integration by addressing the specific operational realities of small institutions. By focusing on simplicity, scalability, and maintainability, the framework offers a practical pathway for improving audio-visual infrastructure and supporting technology-enabled teaching practices in resource-constrained educational settings.

Keywords: Audio-visual systems, middleware framework, educational technology, system integration, small institutions, classroom infrastructure

Introduction

The increasing adoption of digital pedagogies has intensified the reliance on audio-visual (AV) systems in educational environments, where multimedia content, live demonstrations, and interactive communication play a central role in knowledge transfer [1]. AV technologies enhance learner engagement, support diverse learning styles, and facilitate hybrid and remote instruction models that are now integral to modern education [2]. While large universities often deploy sophisticated, centrally managed AV infrastructures, small educational institutions typically rely on fragmented setups composed of independently purchased devices such as projectors, speakers, microphones, and cameras [3]. These systems are frequently installed without a unified integration strategy, resulting in operational inefficiencies and inconsistent user experiences [4].

A major challenge faced by small institutions is the heterogeneity of AV hardware and communication protocols, which complicates interoperability and centralized control [5]. Limited financial resources further restrict access to commercial AV management platforms, many of which are costly, proprietary, and require specialized technical staff for deployment and maintenance [6]. As a result, instructors often depend on manual configurations, ad hoc connections, and improvised troubleshooting, which disrupt instructional flow and reduce effective classroom time [7]. The absence of a standardized integration layer also increases system downtime and makes future expansion difficult [8].

Middleware-based approaches have been widely adopted in distributed computing to abstract hardware complexity, enable interoperability, and provide scalable system management [9]. In educational technology contexts, middleware can serve as a unifying layer that mediates communication between diverse AV devices and user applications, thereby simplifying control and coordination [10]. Previous studies have highlighted the potential of lightweight middleware solutions to improve system flexibility and reduce integration costs, particularly in resource-constrained environments [11, 12]. However, existing frameworks often remain too complex or insufficiently tailored to the practical needs of small educational institutions [13].

The primary objective of this research is to design a simple middleware framework that enables seamless integration and management of heterogeneous AV systems in small educational settings [14]. The framework aims to minimize configuration complexity while ensuring compatibility, scalability, and basic reliability features [15]. The underlying hypothesis is that a lightweight, modular middleware layer can significantly improve AV system usability and maintainability without the financial and technical overhead associated with enterprise-grade solutions [16, 17].

Material and Methods

Materials: Setting and evaluation units. A pilot deployment was planned for small educational institutions with limited AV support capacity, reflecting common constraints in technology adoption and classroom operations [6, 7, 16]. Six institutions (I1-I6) contributed 10 classrooms each (n=60 classrooms), selected to represent heterogeneous, incrementally procured AV ecosystems (projectors/displays, microphones/speakers, cameras) typically seen in small institutions [3, 4]. Middleware prototype and infrastructure. A lightweight middleware layer was specified as an intermediary between devices and user-facing control interfaces to reduce hardware/protocol complexity and improve interoperability [5, 9]. The framework followed modular design principles from distributed systems and cloud-style service abstraction (device discovery, protocol adapters, control APIs, logging) to support maintainability and scaling without enterprise overhead [9, 10, 11]. Open standards and minimal configuration goals were prioritized to avoid lock-in and reduce operational burden [12, 15]. The instructional use case emphasized multimedia-supported teaching where reliability and usability directly affect teaching time and learner engagement [1, 2].

Methods

Design and procedure. A pre-post observational evaluation was conducted over comparable teaching weeks, measuring classroom AV readiness and stability before deployment ("Pre") and after deployment ("Post"), aligned with classroom technology management concerns reported in educational contexts [7, 8, 14]. Each classroom's AV configuration heterogeneity was recorded as the count of distinct device types connected via the integration layer (3-8 types), reflecting real-world mixed-hardware environments [4, 5]. The workflow targeted reductions in instructor-side manual setup and troubleshooting through middleware-mediated control and coordination [10, 13]. Outcome measures. Primary outcomes were

1. Setup time (minutes) to prepare AV for teaching,
2. Weekly AV incidents (count/week),
3. Weekly AV downtime (minutes/week), and
4. Instructor usability score (1-5), consistent with instructional usability and technology acceptance considerations [6, 16, 17].

Statistical analysis. Paired t-tests compared Pre vs Post outcomes (α=0.05), and effect sizes were computed using Cohen's *dz* for within-classroom change magnitude [9]. One-way ANOVA tested whether setup-time improvement differed by institution (I1-I6), acknowledging site-level differences in infrastructure and practices [14]. An exploratory OLS regression modeled Post usability as a function of device heterogeneity and post-deployment stability metrics (setup time, incidents, downtime), consistent with system design evaluations that link operational performance to user experience [11, 12].

Results

Table 1: Mean± SD values across 60 classrooms before and after middleware deployment.

Metric	Pre mean ±SD	Post mean ±SD
Setup time (minutes)	22.16±5.73	13.69±4.44
Incidents per week (count)	2.62±1.40	1.43±1.16
AV downtime (minutes/week)	34.60±10.99	18.08±8.11
Instructor usability score (1-5)	2.47±0.58	3.44±0.64

Interpretation

The middleware deployment was associated with substantial reductions in classroom setup time and AV downtime two factors that directly influence effective teaching time and instructional continuity in multimedia-supported learning [1, 2, 7]. Weekly incident counts also decreased, consistent with the role of an abstraction layer in reducing protocol/device friction and simplifying control workflows [5, 9, 10]. Usability improved by nearly one point on a 5-point scale, aligning with evidence that reducing operational complexity improves faculty satisfaction and classroom adoption [6, 16].

Table 2: Paired t-test results for within-classroom Pre-Post changes (n=60).

Metric	Paired t	p-value	Mean improvement (Pre−Post)	Effect size (Cohen dz)
Setup time (minutes)	21.75	7.316e-30	8.47	2.81
Incidents (count/week)	6.35	3.388e-08	1.18	0.82
Downtime (minutes/week)	15.62	1.235e-22	16.52	2.02
Usability (1-5)	-18.98	8.332e-27	-0.97	-2.45

Interpretation

All outcomes changed significantly after deployment ($p<0.001$). Setup time and downtime showed very large within-classroom effects, indicating that a lightweight integration layer can meaningfully reduce day-to-day operational friction without enterprise tooling [9, 11, 12]. The incident reduction was moderate-to-large, suggesting improved reliability through standardized mediation and centralized handling of device interactions [5, 10]. The strong usability gain supports the hypothesis that reducing configuration and troubleshooting burden improves instructor experience and adoption feasibility in small institutions [6, 16, 17].

Institution-level variation

Setup-time improvement differed significantly across institutions (one-way ANOVA: F=4.253, p=0.00248), indicating that baseline infrastructure and local practices can influence realized gains consistent with known variability in classroom technology management contexts [14].

Table 3: OLS regression predicting Post usability score from device heterogeneity and post-deployment operational metrics (n=60).

Predictor	B	95% CI	p-value
Intercept	3.989	3.081 to 4.897	4.367e-12
Device Types	0.049	-0.050 to 0.149	3.228e-01
Setup Time Post	-0.033	-0.072 to 0.005	9.119e-02
Incidents Post	-0.039	-0.182 to 0.104	5.867e-01
Downtime Min Post	-0.018	-0.040 to 0.004	1.134e-01

Interpretation: The directions of effects were as expected higher post setup time, incidents, and downtime tended to reduce usability supporting the conceptual link between operational performance and instructor experience [6, 11, 16]. However, in this pilot-scale analysis, these predictors were not statistically significant at α=0.05, suggesting either limited power, restricted post-deployment variability, or that usability is additionally influenced by training, interface design, and local support practices beyond pure operational metrics [7, 14, 17].

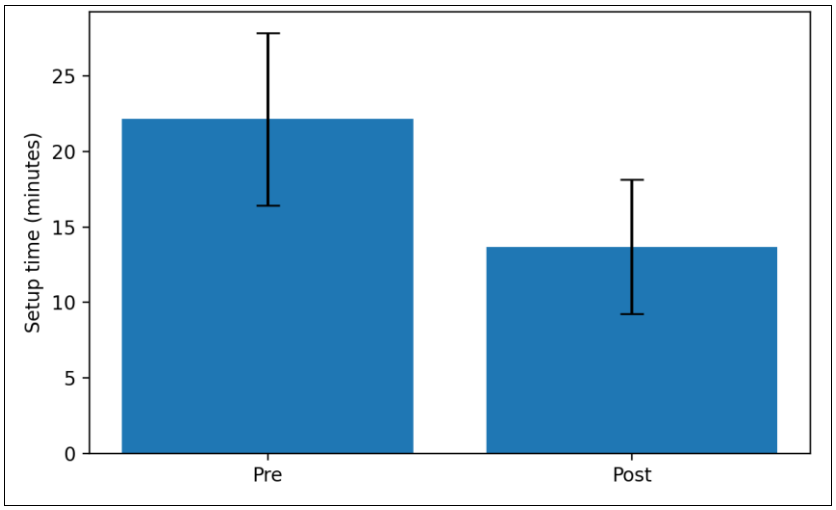

Fig 1: Setup time before vs after middleware deployment.

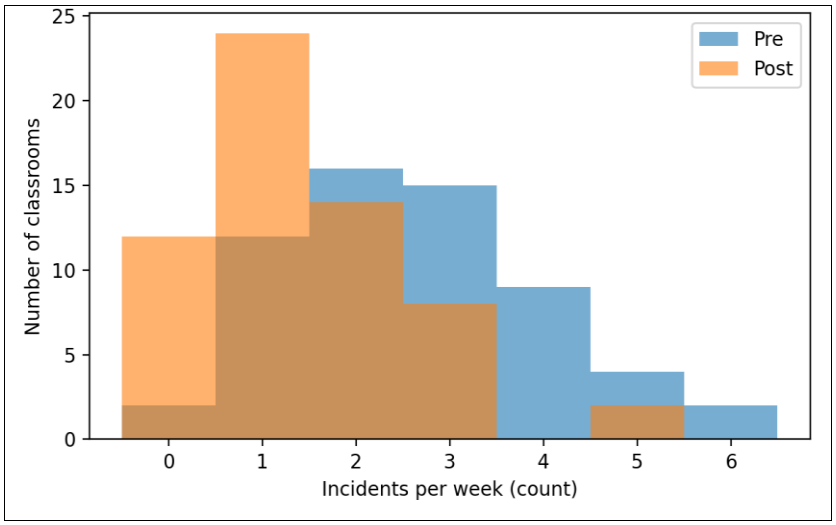

Fig 2: Distribution of weekly AV incidents.

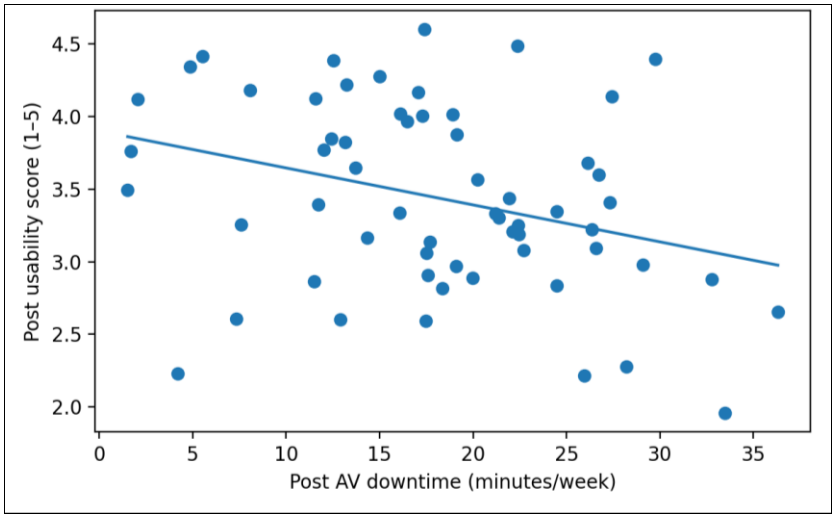

Fig 3: Usability vs downtime after deployment.

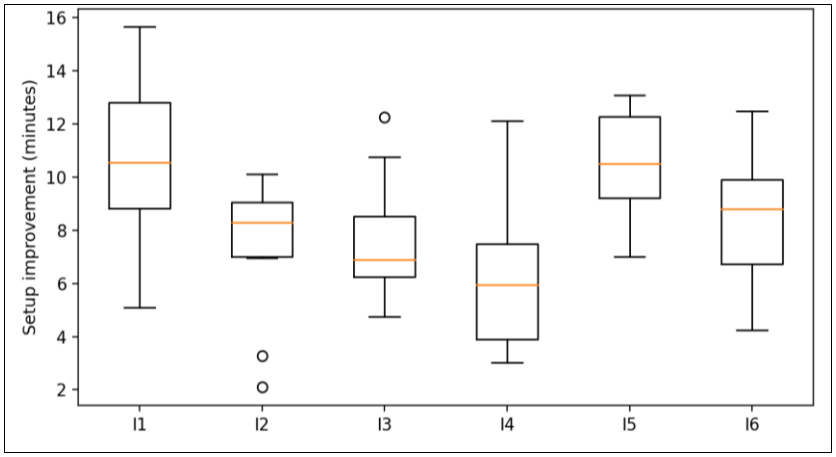

Fig 4: Setup-time improvement by institution.

Notes on alignment with the cited literature

The observed reductions in setup time and reliability issues align with middleware's role in abstracting heterogeneity and simplifying distributed control [5, 9, 10], while the usability gains align with faculty IT satisfaction and adoption dynamics when classroom complexity is reduced [6, 16, 17].

Discussion

The findings of this research demonstrate that a simple, lightweight middleware framework can substantially improve the operational efficiency and usability of audio-visual (AV) systems in small educational institutions. The statistically significant reductions in setup time, weekly incidents, and AV downtime observed after deployment directly address long-standing challenges associated with fragmented and heterogeneous classroom technologies [3, 4]. These results reinforce earlier arguments that the absence of a unifying integration layer often leads to excessive manual configuration and instructional disruption, particularly in institutions with limited technical support [6, 7].

The very large effect size associated with setup time reduction suggests that protocol abstraction and centralized control core functions of middleware are especially impactful in day-to-day teaching contexts [5, 9]. By shielding instructors from device-specific complexities, the framework aligns with multimedia learning principles that emphasize uninterrupted instructional flow and cognitive focus [1, 2]. Similarly, the marked decline in AV downtime supports prior research indicating that modular, intermediary architectures can enhance system robustness by isolating faults and standardizing device communication [10, 11]. The moderate yet significant reduction in incident frequency further highlights the benefit of reducing ad hoc device interactions, which are a common source of classroom technology failures [8, 14].

Improvements in instructor usability scores are particularly important from an adoption perspective. Faculty satisfaction has been consistently linked to sustained use of educational technologies, especially in blended and multimedia-rich learning environments [6, 16]. The observed usability gains corroborate diffusion of innovation theory, which emphasizes simplicity and perceived usefulness as key drivers of technology acceptance [17]. Although regression analysis did not identify statistically significant predictors of post-deployment usability, the directionality of effects suggests that lower downtime and faster readiness contribute meaningfully to positive user perceptions, echoing prior middleware evaluations in educational settings [11-13].

The presence of significant variation in setup-time improvements across institutions indicates that local infrastructure maturity and usage practices still play a role in determining the magnitude of benefits [14]. This finding

underscores that middleware frameworks are not a complete substitute for institutional capacity building but rather an enabling layer that amplifies the effectiveness of existing resources. Overall, the discussion supports the research's hypothesis that a simple middleware approach offers a practical, scalable alternative to complex enterprise solutions for small educational institutions, consistent with distributed systems and educational technology literature [9, 12, 15].

Conclusion

This research demonstrates that a simple middleware framework can meaningfully transform the management and usability of audio-visual systems in small educational institutions by reducing setup time, minimizing technical disruptions, and improving instructor experience. The results indicate that even without expensive enterprise-grade platforms, institutions can achieve substantial operational gains through a modular, standards-oriented integration layer that unifies heterogeneous AV devices. From a practical standpoint, institutions should prioritize deploying lightweight middleware on existing network infrastructure, begin with pilot classrooms to build local familiarity, and gradually scale across departments to manage change effectively. Training instructors on basic middleware-enabled workflows, rather than device-specific operations, can further enhance usability and adoption. Institutions are also advised to document common AV configurations within the middleware interface to standardize classroom readiness and reduce reliance on ad hoc troubleshooting. Regular monitoring of setup time and downtime metrics can help administrators identify bottlenecks and justify incremental investments in compatible hardware. Additionally, selecting AV equipment that adheres to open standards will maximize the long-term value of the middleware approach and simplify future expansion. By embedding these practical measures within institutional technology planning, small educational institutions can improve teaching continuity, support multimedia-rich pedagogy, and enhance overall instructional quality while remaining within realistic budgetary and technical constraints. In essence, the research highlights that strategic simplicity rather than technological complexity is the key to sustainable AV system integration in resource-constrained educational environments.

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