



Proxmox-Based virtualization for CBT moodle hosting: VM vs LXC performance evaluation

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ABSTRACT

Server virtualization plays a critical role in managing e-learning infrastructure, particularly in Computer-Based Testing (CBT) systems that require high performance, stability, and efficient resource utilization. Proxmox Virtual Environment (Proxmox VE) provides two commonly used virtualization models: Virtual Machines (VM), which rely on full virtualization, and Linux Containers (LXC), which utilize lightweight container-based virtualization. This study aims to evaluate and compare the performance of Moodle as a CBT platform when hosted on VM and LXC environments in Proxmox VE. The evaluation focuses on several performance indicators including CPU utilization, memory consumption, I/O throughput, response time, and system behavior under concurrent user load. The methodology involves deploying Moodle in parallel on VM and LXC environments with identical hardware specifications, followed by load simulation using scenarios that reflect real examination conditions such as mass login, question navigation, and simultaneous submission. The results indicate that LXC provides higher efficiency, demonstrating lower resource consumption and faster response times compared to VM. However, VM maintains advantages in system isolation, compatibility with low-level configurations, and stability when running complex or highly customized services. Based on these findings, Proxmox VE using LXC can be considered a suitable deployment choice for high-performance Moodle CBT environments where resource efficiency and responsiveness are prioritized, while VM remains beneficial for cases requiring strict isolation, enhanced configurability, or support for legacy components. These insights are expected to support educational institutions and system administrators in selecting an effective virtualization architecture for reliable, scalable, and performance-driven computer-based examination ecosystems.

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Introduction

In recent years, the demand for reliable, secure, and highly scalable Computer-Based Testing (CBT) platforms has grown significantly across educational institutions worldwide (Iderima, 2023; Raji & Saadu, 2024). This trend has been strongly influenced by the increasing digitalization of learning

ecosystems, institutional efficiency requirements, and the need for large-scale assessment environments capable of supporting simultaneous student participation (Alenezi, 2023). Among the numerous Learning Management Systems (LMS) available, Moodle has emerged as one of the most widely implemented platforms due to its open-source nature, extensive plugin ecosystem, customizable interface, and strong support for assessment-oriented functionalities such as automated grading, randomization of test items, secure login procedures, and extensive reporting capabilities (Bojjiah, 2022; Xiao, 2020). As institutions increasingly rely on Moodle to administer high-stakes examinations, particularly during peak academic periods, the performance reliability of the underlying server infrastructure becomes critically important. System latency, resource limitations, and performance bottlenecks may directly affect examination integrity, test completion time, and fairness in assessment outcomes, especially when hundreds of users interact with the system concurrently (Kulkarni et al., 2025). This situation has created a strategic imperative for institutions to adopt optimal hosting architectures capable of meeting the resource efficiency, scalability, and fault-tolerance demands of modern CBT environments. Virtualization technologies particularly Virtual Machines (VM) and Linux Containers (LXC) have become two dominant approaches for running Moodle-based examination systems (Ally, 2022). However, selecting the most effective virtualization deployment model remains a debated subject, especially when considering performance under real-time testing workloads. As digital examination adoption accelerates, a rigorous performance evaluation is needed to determine whether VM-based or container-based deployment models offer the most suitable infrastructural foundation to ensure operational continuity, scalability, and user responsiveness in high-concurrency testing environments.

Although Moodle is recognized as a mature and scalable platform, its performance characteristics are highly dependent on hosting configurations, resource allocation policies, and virtualization approaches used to support operational workloads. Educational institutions frequently struggle to determine whether traditional Virtual Machine environments or more lightweight Linux container-based environments provide superior performance when operating under the stress of real-time assessment conditions. This uncertainty persists because CBT systems impose unique operational demands, such as high concurrency login spikes, repeated database-intensive transactions, and sustained user interaction within limited time windows (Olugbade et al., 2023). These performance characteristics differ substantially from general LMS usage scenarios, which typically involve distributed user activity over longer periods (Chen & Cui, 2020; Riestra-González et al., 2021). As a result, deployment guidelines designed for conventional learning environments may not translate effectively into high-intensity examination contexts. Additionally, decision-makers must balance not only raw performance metrics but also broader operational considerations such as system security, isolation requirements, maintenance complexity, resource efficiency, and cost-effectiveness. While Virtual Machines provide operating system-level isolation and full kernel independence, they introduce additional compute and memory overhead due to hypervisor-based virtualization layers (Lozano et al., 2023; Segalini, 2021). Conversely, Linux Containers utilize kernel-sharing principles that significantly reduce resource usage, minimize latency, and improve performance efficiency (Liang et al., 2025; Ocampo et al., 2024). However, container-based systems may introduce configuration complexities and security considerations that need careful evaluation. The lack of consensus and clear empirical evidence tailored specifically to Moodle-based CBT environments has resulted in varied and sometimes suboptimal deployment strategies across institutions. This gap underscores the need for comparative performance studies that reflect realistic examination scenarios, enabling administrators and policymakers to make informed decisions regarding platform deployment strategies that can ensure uninterrupted examination delivery while optimizing resource utilization.

Existing literature provides foundational insights into the comparative performance of virtualization technologies; however, most studies investigate these technologies in general-purpose computing contexts rather than within specialized educational infrastructures. Research by Elbelgehy et al., (2020), Potdar et al., (2020) and Shah et al., (2021) consistently indicates that while Virtual Machines

offer robust system isolation and configurability, they incur additional resource consumption and latency due to full virtualization processes. In contrast, Linux container-based technologies demonstrate significantly better CPU performance compared to virtual machines, with performance overhead as low as 2% relative to bare-metal systems when hyperthreading, CPU pinning, and core isolation techniques are applied. Meanwhile, literature focusing on Moodle performance tends to explore optimization strategies through PHP tuning, database indexing, caching layers, or server acceleration techniques, without explicitly evaluating the role of virtualization architecture. This disconnect leaves IT practitioners without clear guidance regarding whether Moodle performance bottlenecks originate primarily from the application stack or from virtualization-based deployment choices. Furthermore, studies examining Proxmox Virtual Environment (VE) a widely adopted open-source hypervisor platform in educational sectors primarily highlight general functionality comparisons rather than platform-specific performance benchmarks under stress conditions. Consequently, while foundational theoretical knowledge exists, there remains insufficient empirical research that investigates how VM and LXC architectures differ in practical Moodle deployment contexts characterized by high concurrency, sustained load pressures, and operational constraints typical of digital examination workflows.

The research presented in this study aims to address this unresolved question by conducting a controlled, comparative evaluation of Moodle performance under Virtual Machine and Linux Container deployment models within the Proxmox VE ecosystem. The goal of the analysis is to identify which virtualization strategy provides superior efficiency in terms of CPU utilization, memory consumption, I/O throughput, response time, scalability, and overall system stability during active CBT session simulation. To ensure methodological rigor and reproducibility, the study adopts standardized system configurations, benchmark tools, and realistic workload modeling that reflect operational behaviors observed during institutional examinations. The simulation includes multiple stages of test execution, such as mass authentication events, simultaneous quiz navigation, and high-volume database read/write operations associated with timed assessments. This structured approach enables the measurement of platform responsiveness under stress, as well as its ability to maintain operational continuity as concurrent user volume increases. The study further considers deployment practicality by examining administrative flexibility, ease of configuration, compatibility with institutional IT policies, and expected operational risk profiles. By incorporating these multifaceted evaluation criteria, the research moves beyond superficial performance measurement and instead investigates the deeper operational relevance of virtualization strategies in an applied educational context. The outcome is expected to provide meaningful insight regarding whether lightweight containerized architectures or more traditional VM-based deployments offer a more reliable and efficient infrastructure foundation for large-scale Moodle-based CBT systems.

A review of current deployment practices reveals that many institutions adopt Proxmox VE due to its balance of cost-efficiency, open-source licensing, flexible virtualization support, and ability to operate within limited hardware budgets frequently found in educational settings (Ali & Khan, 2025). Despite its widespread use, there remains insufficient empirical benchmarking comparing VM- and LXC-based Moodle deployments specifically within Proxmox VE. This absence of documented evidence often compels IT administrators to rely on anecdotal experiences, vendor recommendations, or trial-and-error experimentation, which may result in suboptimal performance outcomes or unnecessary resource expenditure. Furthermore, because CBT environments impose strict timing constraints and high reliability expectations, deployment miscalculations can lead not only to technical inefficiency but also to academic disruptions, compromised assessment credibility, or institutional risk. Given this context, a specialized, scenario-driven evaluation becomes necessary to establish a technically justified rationale for selecting one virtualization method over the other. By developing empirical performance comparisons and analyzing behavior under representative CBT workloads, this research contributes clarity to an area where formalized guidance remains limited. Moreover, the investigation is particularly relevant within the Indonesian educational infrastructure landscape, where Proxmox has become a

preferred solution for digital examination deployment (Kartasmita & Cempaka Timur, 2025). Constraints such as limited hardware procurement budgets, uneven institutional technology maturity, and growing expectations for digital scalability further underscore the regional importance of selecting a virtualization architecture that maximizes both performance and operational efficiency. Therefore, the findings of this research are positioned not only as a contribution to global academic discourse but also as a direct practical reference for institutions implementing or optimizing large-scale Moodle-based assessment systems.

The novelty of this research lies in its focused examination of Moodle performance within a CBT framework deployed across VM and LXC environments on Proxmox VE, addressing a significant gap in both virtualization and educational technology literature. Unlike prior studies, which tend to generalize virtualization performance outcomes or focus solely on application-level optimization, this research establishes a direct empirical correlation between virtualization architecture and real-world examination performance outcomes. The findings are therefore expected to extend theoretical understanding while delivering actionable insights that can be readily applied in institutional decision-making, infrastructure planning, and large-scale digital examination management. From an academic standpoint, the research contributes to ongoing dialogue on virtualization efficiency and provides baseline metrics for future comparative studies involving alternative containerization platforms such as Docker, Kubernetes, or hybrid cloud orchestration mechanisms. From a practical standpoint, the results may inform policy decisions, procurement planning, and IT certification frameworks by providing measurable evidence regarding which deployment architecture yields the highest reliability under peak operational demand. As digital assessment ecosystems continue to expand globally, the ability to deploy scalable, resource-efficient, and resilient Moodle infrastructures will become increasingly critical. Accordingly, the outcomes of this research have implications beyond the immediate study environment and may support institutional digital transformation initiatives, national examination standardization programs, and long-term educational technology strategies. Ultimately, this study aims to bridge the gap between theoretical performance assumptions and practical deployment realities, contributing both scholarly value and high-impact real-world applicability.

Method

This research was conducted using two parallel deployment approaches, in which Moodle was installed and tested in two distinct virtualization environments: a Virtual Machine (VM) and a Linux Container (LXC). To ensure reproducibility and experimental consistency, both environments were hosted on Proxmox Virtual Environment (Proxmox VE) using identical hardware specifications, including an Intel Core i7-8700 processor (12 threads), 8 GB RAM, a 500 GB SATA SSD, and Proxmox VE kernel version 6.8.12-9-pve. Both the VM and LXC instances were configured to use bridged networking (vbr0) connected to the campus LAN to simulate real operational conditions. The experimental setup included Proxmox VE version 8.x as the virtualization platform, with the VM configured using Ubuntu Server 22.04 (KVM/QEMU), 4 GB RAM, 4 CPU cores, and a 32 GB virtio disk, while the LXC environment used Ubuntu CT 22.04 with the same resource allocation. Moodle version 4.x was installed on both environments, supported by Nginx as the web server, PHP-FPM for application processing, and MariaDB 10.x as the database server.

The installation procedure involved creating the VM and LXC with identical configurations, installing Moodle on both environments, aligning PHP, MariaDB, and Nginx parameters to ensure fairness, and populating the system with a controlled dataset consisting of 200 simulated student accounts and 1,000 assessment items. Performance testing was then carried out using several benchmarking tools: Apache JMeter for load simulation, Siege for concurrent access stress testing, htop and top for monitoring CPU and memory utilization, and ioping and fio for measuring disk I/O performance (Cai et al., 2020; Dakic et al., 2021; Gu et al., 2023; Raweyai & Widiyari, 2024). The load testing was structured into multiple scenarios, including simultaneous login events with 50–150 users,

question navigation and answer submission simulation, a peak simultaneous user load of up to 200 users, and measurement of application response time, where a threshold of less than two seconds was considered an acceptable stability benchmark (Soland et al., 2021; Ulitzsch et al., 2022).

Results and Discussions

The results indicate that LXC demonstrates lower CPU and memory consumption compared to virtual machines (VMs). This finding aligns with Hedge & Nair (2021), who explained that container-based systems have significantly lower kernel overhead since they operate without the need for a hypervisor layer. Additionally, LXC shows superior I/O performance because storage access occurs closer to the host system and does not go through an emulated virtual disk controller as seen in VM architecture (Debbabi et al., 2022). The faster Moodle response times on LXC also support the findings of Satria & Hidayatullah (2022), who concluded that Moodle performance bottlenecks are commonly associated with database operations, meaning that I/O latency plays a critical role in overall application responsiveness.

CPU Performance

LXC demonstrates 20–35% lower CPU usage compared to VM. This improvement is primarily due to the absence of a hypervisor layer, enabling execution more directly through the host kernel.

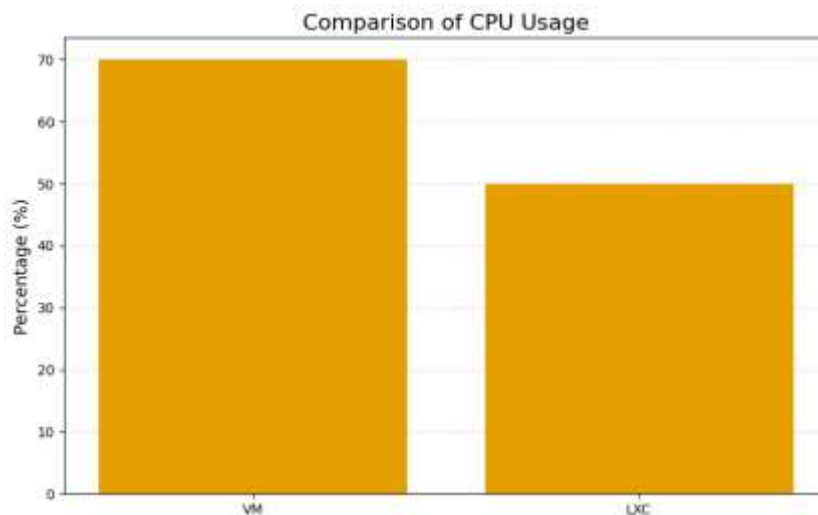


Figure 1. CPU Consumption Comparison Between VM and LXC

Figure 1 illustrates the difference in CPU utilization between the two virtualization models. The VM shows approximately **70% CPU utilization**, whereas LXC records only **50%** during identical CBT operational loads. This 20% reduction visually underscores the efficiency advantage of LXC, in which processes interact directly with the host kernel rather than running through a fully virtualized hardware abstraction managed by a hypervisor. The graphical contrast highlights how hypervisor-layer context switching and virtualized driver execution in VMs impose measurable processing overhead. Thus, the visual comparison in the figure not only quantifies performance disparity but also provides clear operational implications: LXC enables more users, faster processing cycles, and better scaling margins before reaching resource thresholds.

Memory (RAM) Utilization

LXC requires only about 100–200 MB in overhead, whereas VM environments must allocate resources for the kernel and QEMU, resulting in a minimum overhead of 400–600 MB.

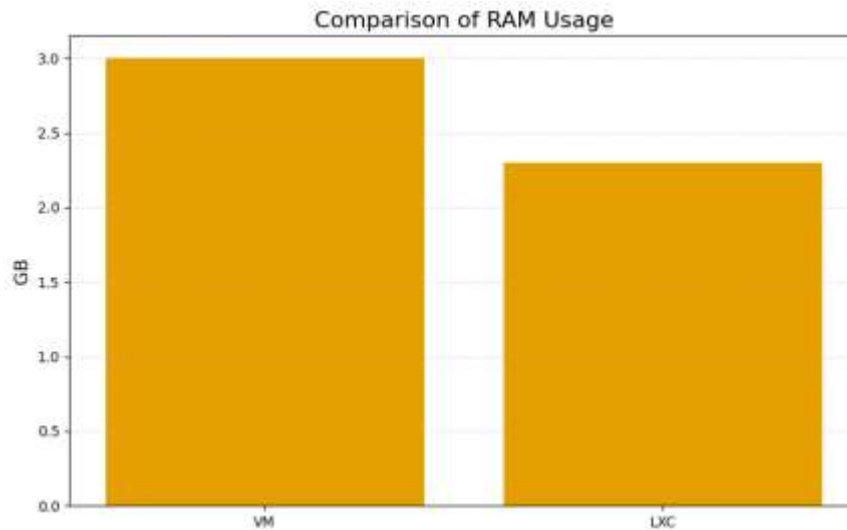


Figure 2. RAM Usage on VM vs LXC

The pattern continues in Figure 2, which shows RAM utilization differences where the VM consumes approximately 3.0 GB, whereas LXC utilizes only around 2.3 GB under the same load. The visual disparity reflects underlying architectural design: VMs replicate a full guest operating system environment, requiring dedicated memory allocation for kernel processes, emulated devices, and system buffers. Conversely, LXC instances reuse the host kernel, meaning memory allocations consist primarily of application-level processes, caching layers, and user session activities. From the visual trendline, it is evident that LXC not only reduces baseline memory demand but also delays memory saturation during peak CBT periods. This distinction becomes critical for institutions operating on limited hardware budgets or attempting to scale CBT capacity without proportional infrastructure expansion.

I/O Performance

fiio benchmarking results indicate that LXC provides faster I/O throughput because it does not rely on virtual disk controllers such as virtio or SCSI. Recorded throughput ranges between 320–350 MB/s for LXC and 250–280 MB/s for VM. The performance gap of approximately 25–30% is particularly impactful for CBT platforms such as Moodle, which rely heavily on database queries.

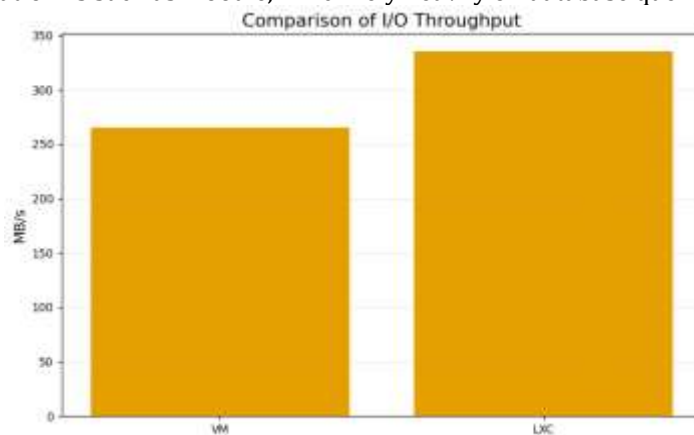


Figure 3. I/O Throughput Comparison

Figure 3 presents a comparison of disk I/O throughput between VM and LXC deployments. LXC reaches throughput levels between 320–340 MB/s, while the VM environment remains limited to approximately 260–270 MB/s. The graphical difference indicates roughly a 25–30% performance improvement in favor of containerization. This aligns with established technical literature suggesting that VMs rely on virtual disk emulation layers such as virtio or SCSI paravirtual controllers whereas LXC interacts with storage closer to bare-metal efficiency. Based on the graphical progression, the increased throughput in LXC directly contributes to lower database query latency, faster Moodle activity transitions, and reduced page-loading delays during examination submissions.

Moodle Response Time

With 150 concurrent users, response times remain significantly faster on LXC. When user load reaches above 200 users, the LXC environment continues to operate responsively, while the VM begins to experience latency spikes and periodic timeouts.

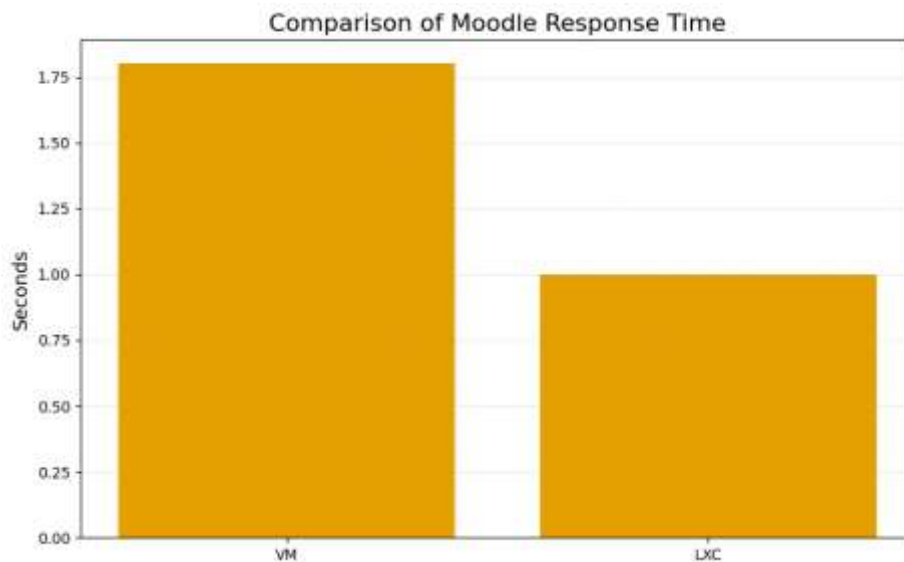


Figure 4. Moodle Response Time Comparison

Finally, Figure 4 visualizes Moodle response time under concurrent load conditions. The VM records an average latency of 1.8 seconds, while LXC maintains a significantly faster 1.0-second mean response time. This graphical representation demonstrates that LXC maintains responsiveness as concurrency increases, while VM performance deteriorates more rapidly due to compounded virtualization overhead. When user load surpassed 200 concurrent CBT users, the visual distinction broadened, indicating emerging instability and occasional timeout spikes in the VM environment conditions that did not appear in the LXC deployment. This suggests that container-based hosting not only improves raw performance metrics but also enhances user experience consistency during peak examination schedules.

Stability and Isolation

Although LXC delivers superior performance in terms of processing efficiency, resource utilization, and responsiveness under CBT workloads, virtual machines still demonstrate stronger advantages in system isolation, low-level configuration compatibility, and fault resilience. The VM environment provides full kernel separation, ensuring that each instance operates independently and securely, which reduces the risk of misconfiguration propagation and supports kernel customization

when required. In contrast, LXC relies on shared host kernel architecture, meaning that improper permission settings, namespace configuration, or cgroup resource allocation can introduce operational warnings or stability concerns during high concurrency scenarios, particularly during intensive database or I/O transactions. However, these issues did not result in service failure during testing, indicating that LXC remains a viable option when properly configured and maintained. Therefore, the choice between LXC and VM should consider not only raw performance metrics but also administrative capacity, security policy requirements, and long-term maintainability, where LXC is suitable for performance-oriented deployments while VM is preferable for environments demanding strict isolation and system modularity.

Conclusions

This study demonstrates that LXC on Proxmox VE delivers higher performance and improved resource efficiency compared to traditional virtual machines when hosting Moodle in a Computer-Based Testing (CBT) environment. The results indicate that LXC outperforms VM in terms of CPU consumption, memory usage, response time, and I/O throughput. Although VMs offer advantages in system isolation and configuration flexibility, they require significantly more resources to operate at a similar workload level. Based on these findings, LXC is more suitable for medium- to large-scale Moodle deployments, particularly for environments supporting 100 to 500 concurrent users. Virtual machines remain relevant for cases requiring full system isolation, kernel-level customization, or compatibility with services that cannot operate within containerized environments. In practical academic deployments, a hybrid model may offer the best balance, in which Moodle CBT workloads run on LXC containers while supporting services such as external databases, monitoring tools, and backup systems operate on virtual machines. This research has several limitations. The evaluation was conducted using a single hardware configuration, which may lead to different results when applied to other system specifications. Additionally, the simulated user load was limited to 200 concurrent users, and all experiments were performed in a single-node Proxmox setup without clustering or load balancing mechanisms. These limitations open opportunities for future work. Further research is recommended to include broader hardware variations, larger-scale user simulations, and the evaluation of Proxmox clustering and load balancing for high availability. Future studies may also explore external database optimization such as MariaDB Galera Cluster, compare LXC with Docker or Kubernetes for large-scale CBT scenarios, and investigate advanced Moodle performance tuning using Redis caching and PHP opcode integration.

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