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Empirical Evaluation of Transforming Traditional Programming Laboratories into PaaS-Based Environments Using CloudBees

Hassan KH Mohamed *
Department of Computer Science, Faculty of Arts and Sciences – Sluk, University of Benghazi, Sluk, Libya

التقييم التجريبي لتحويل مختبرات البرمجة التقليدية إلى بيئات قائمة على منصة كخدمة (*PaaS*) باستخدام *CloudBees*

حسن خليفة محمد *
قسم علوم الحاسوب، كلية الآداب والعلوم - سلوق، جامعة بنغازي، سلوق، ليبيا

*Corresponding author: hasanelfakhari@uob.edu.ly

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Abstract:
The rapid evolution of cloud computing has fundamentally transformed the provisioning and consumption of computational resources in higher education institutions. Traditional programming laboratories require continuous investment in hardware, licensed software, and technical maintenance, which often limits their scalability and long-term sustainability. This study presents a controlled empirical evaluation of transforming traditional programming laboratories into Platform as a Service (PaaS)-based environments using CloudBees. The evaluation focuses on two critical quality attributes: system responsiveness and cost efficiency. A cross-over experimental design was conducted with 40 undergraduate students enrolled in an Object-Oriented Programming course. System responsiveness was assessed using task completion time and the Application Performance Index (Apdex), while cost efficiency was evaluated through a structured per-student cost model. The results indicate that PaaS-based programming laboratories significantly improve responsiveness and achieve notable cost reductions, approximately 28% per student, when compared to traditional laboratory environments. These findings provide empirical evidence supporting the feasibility and effectiveness of adopting cloud-based, PaaS-oriented programming laboratories in higher education institutions.

Keywords: Cloud Computing; Platform as a Service (PaaS); Programming Laboratories; Empirical Evaluation; System Responsiveness; Cost Model.

الملخص:
أدى التطور السريع للحوسبة السحابية إلى إحداث تحول جذري في توفير واستهلاك الموارد الحسابية في مؤسسات التعليم العالي. تتطلب مختبرات البرمجة التقليدية استثماراً مستمراً في الأجهزة والبرمجيات المرخصة والصيانة التقنية، مما يحد غالباً من قابليتها للتوسع واستدامتها على المدى الطويل. تقدم هذه الدراسة تقييماً تجريبياً مضبوطاً لتحويل مختبرات البرمجة التقليدية إلى بيئات قائمة على نظام المنصة

كخدمة (PaaS) باستخدام CloudBees. يركز التقييم على صفتين حرجتين للجودة: استجابة النظام وكفاءة التكلفة. أُجري تصميم تجريبي متقاطع مع 40 طالباً من طلاب المرحلة الجامعية المسجلين في دورة البرمجة كائنية التوجه. تم تقييم استجابة النظام باستخدام وقت إكمال المهام ومؤشر أداء التطبيق (Apdex)، بينما تم تقييم كفاءة التكلفة من خلال نموذج تكلفة مهيكل لكل طالب. تشير النتائج إلى أن مختبرات البرمجة القائمة على PaaS تعمل بشكل كبير على تحسين الاستجابة وتحقيق تخفيضات ملحوظة في التكاليف، بنسبة تقارب 28% لكل طالب، مقارنة ببيئات المختبرات التقليدية. توفر هذه النتائج أدلة تجريبية تدعم جدوى وفعالية اعتماد مختبرات البرمجة القائمة على السحابة والموجهة نحو PaaS في مؤسسات التعليم العالي.
الكلمات المفتاحية: الحوسبة السحابية؛ المنصة كخدمة (PaaS)؛ مختبرات البرمجة؛ التقييم التجريبي؛ استجابة النظام؛ نموذج التكلفة.

1. Introduction

Practical laboratory sessions play a central role in computer science education, particularly in programming-oriented courses, where students acquire hands-on experience, reinforce theoretical concepts, and develop problem-solving skills (Radianti et al., 2020).

Cloud computing has become a foundational technology in modern educational systems, offering flexible architectures, diverse applications, and new pedagogical opportunities, while also introducing technical and organizational challenges (Alakuu & Dake, 2025). Figure 1 illustrates the general architecture of cloud computing, showing the three main service layers and typical components within each layer.

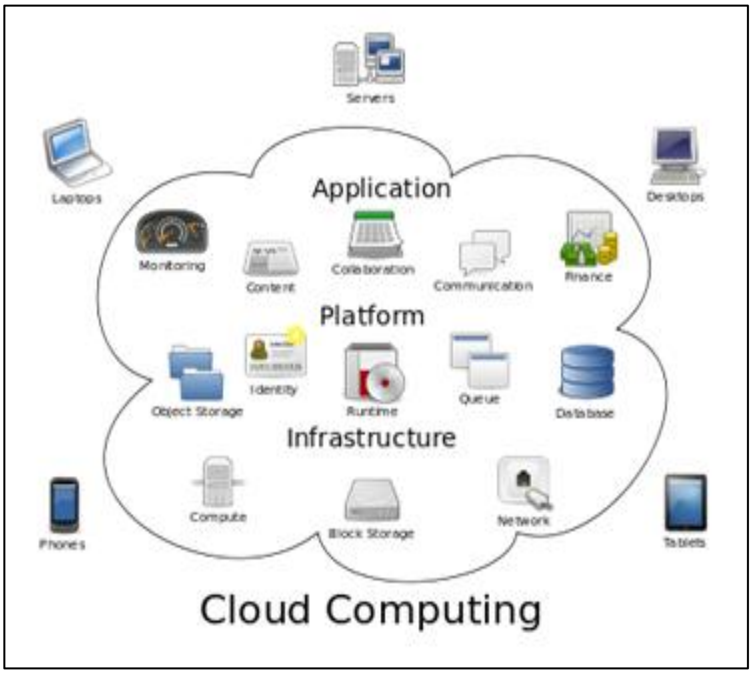

Figure 1: Architecture of Cloud Computing

Among cloud computing service models, SaaS, PaaS, and IaaS provide different levels of abstraction. PaaS is particularly suitable for programming education as it allows students to focus on development while the infrastructure is managed by the provider. Figure 2 illustrates the cloud computing stack and the relationship between these service models.

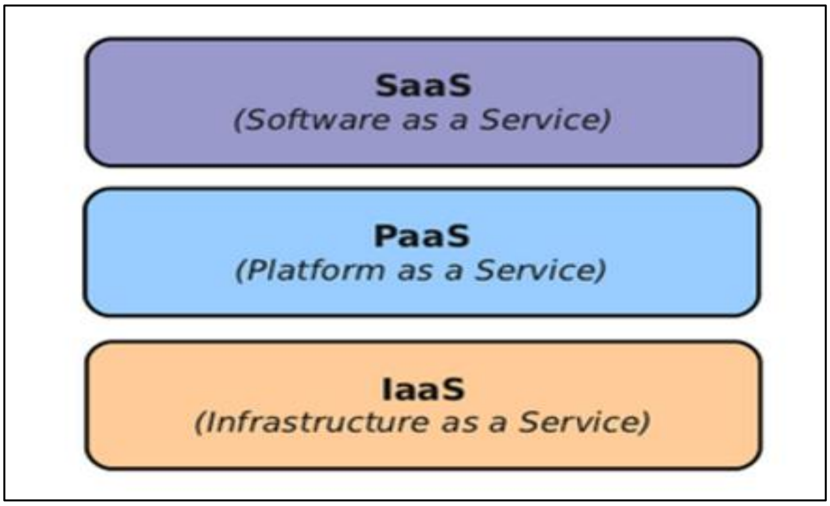

Figure 2: Cloud Computing Stack.

Maintaining traditional programming laboratories requires continuous investment in hardware upgrades, software licensing, technical support, and energy consumption, which often constrains scalability and long-term sustainability in higher education institutions.

Cloud computing provides on-demand access to shared computing resources through the Internet, enabling enhanced scalability, flexibility, and cost efficiency for users. It encompasses multiple service models, including Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Among these models, PaaS has proven particularly effective in educational environments, especially for programming instruction, as it allows learners to concentrate on software development activities while minimizing concerns related to infrastructure configuration and management (Hilario et al., 2024).

Despite the increasing adoption of cloud technologies in educational settings, there remains a scarcity of controlled empirical studies that systematically evaluate the transformation of traditional programming laboratories into PaaS-based environments. Previous research has primarily focused on general online learning engagement and usability (Halabi et al., 2014; Harrati et al., 2016), highlighting the importance of user-centered metrics such as responsiveness, satisfaction, and interaction patterns. However, rigorous assessments of PaaS-based programming laboratories, particularly regarding system responsiveness and cost efficiency, are still limited, underscoring the need for empirical investigations that integrate both technical and learner-perceived outcomes. This study addresses this gap by empirically evaluating the transformation of traditional programming laboratories into PaaS-based environments using CloudBees.

2. Related Work

Cloud computing adoption in education has been widely examined, with studies highlighting its potential to enhance scalability and resource utilization. Virtual and cloud-based laboratories improve accessibility and collaborative learning experiences by enabling activities beyond physical laboratory limitations.

However, empirical research has predominantly focused on IaaS and SaaS, while systematic evaluations of PaaS-based programming laboratories remain scarce. Many existing studies emphasize system-level performance with limited attention to user-centered metrics such as perceived responsiveness and satisfaction. For instance, Halabi et al. (2014) provided evidence that engagement with online materials correlates with improved academic performance. Similarly, Harrati et al. (2016) demonstrated that usage-based metrics combined with task-oriented analyses provide a more accurate understanding of learner experience. Furthermore, Nayar and Kumar (2018) demonstrated potential cost savings associated with cloud solutions, although comprehensive cost models for institutional contexts remain limited.

3. Research Objectives and Questions

The primary objective is to evaluate the feasibility of adopting PaaS-based programming laboratories in higher education.

a. **RQ1**: Does a PaaS-based programming laboratory exhibit different system responsiveness compared to a traditional laboratory environment?
b. **RQ2**: Does transforming a traditional programming laboratory into a PaaS-based environment reduce operational costs?

Hypotheses:

a. **$H0_1$**: There is no statistically significant difference in responsiveness between traditional and PaaS-based laboratories.
b. **$H1_1$**: There is a statistically significant difference in responsiveness between traditional and PaaS-based laboratories.
c. **$H0_2$**: There is no statistically significant difference in operational costs between traditional and PaaS-based laboratories.
d. **$H1_2$**: There is a statistically significant difference in operational costs between traditional and PaaS-based laboratories.

4. Experimental Design

a. **4.1 Participants**: Forty undergraduate students in an Object-Oriented Programming course participated. All possessed comparable experience in Java programming.
b. **4.2 Experimental Setup**: A cross-over experimental design was employed to minimize individual differences. In phase one, Group A used the traditional lab while Group B used the PaaS lab; they switched environments in phase two.
c. **4.3 Programming Tasks**: Tasks covered fundamental concepts including class design, inheritance, polymorphism, encapsulation, and abstraction.

5. Measurement and Instrumentation

Responsiveness was assessed using the Application Performance Index (Apdex).

a. **5.1 Responsiveness Metrics**: Evaluated using task completion time (minutes) and Apdex.
b. **5.2 Cost Metrics**: Evaluated using a per-student, per-semester cost model covering capital and operational expenditures.

6. Cost Model

The evaluation follows a structured model aligned with previous research.

a. **Traditional Laboratory Cost (TLC)**: Hardware + Software + Maintenance + Energy/Space.
b. **Cloud-based Laboratory Cost (CLC)**: PaaS Subscription + Network + Administrative Overhead.

Table 1: Cost Model Example (USD per student)

Component	Traditional Lab (USD)	Cloud Lab (USD)
Hardware & Software	140	0
Maintenance	65	25
Energy & Space	40	15
PaaS Subscription	0	80
Total	245	175

7. Results

7.1 Task Completion Time

The analysis of task completion time indicates a notable improvement in efficiency within the cloud-based environment. Students operating in the PaaS environment completed their programming tasks significantly faster than those in the traditional laboratory setting.

Table 1: Statistical Summary of Task Completion Time (Minutes)

Environment	Mean (min)	Std. Deviation	Minimum	Maximum
Traditional Lab	95	12	78	125
Cloud-based Lab	78	10	60	98

7.2 Apdex Scores

The Application Performance Index (Apdex) was employed to quantify user-perceived responsiveness. The scores reflect a higher level of satisfaction and system efficiency in the PaaS-based environment.

Table 2: Apdex Scores for System Responsiveness

Environment	Mean Apdex	Std. Deviation	Minimum	Maximum
Traditional Lab	0.71	0.07	0.55	0.85
Cloud-based Lab	0.82	0.05	0.72	0.90

7.3 Cost Analysis

The economic evaluation demonstrates the financial viability of transitioning to a cloud-based model, with significant reductions in capital expenditures (CAPEX).

Table 3: Detailed Operational and Capital Cost Breakdown (Per Student)

Cost Component	Traditional Lab (USD)	Cloud Lab (USD)	Variance (%)
Hardware Resources	120	0	-100%
Software Licenses	20	0	-100%
Maintenance & Support	65	25	-61.5%
Energy & Space	40	15	-62.5%
PaaS Subscription	0	80	N/A
Total Cost	**$245**	**$175**	**-28.6%**

A paired t-test was conducted to verify the findings, indicating a statistically significant difference in responsiveness ($p < 0.05$) in favor of cloud-based laboratories.

8. Threats to Validity

In accordance with the framework by Takona (2024), the following threats to validity were identified and addressed:

- **Internal Validity:** To mitigate potential biases arising from individual differences or learning curves, a cross-over experimental design was implemented (Radianti et al., 2020).

- **External Validity:** The generalizability of these results may be limited as the study was restricted to a single course and institution (Nayar & Kumar, 2018).
- **Construct Validity:** This was ensured by utilizing standardized and peer-validated metrics, specifically task completion time and the Apdex index (Halabi et al., 2014; Harrati et al., 2016).
- **Conclusion Validity:** The reliability of the conclusions is supported by the application of rigorous statistical methods, including paired t-tests and descriptive statistics (Ataş & Gungor, 2014).

9. Discussion

The empirical findings of this study provide robust evidence that PaaS-based programming laboratories significantly outperform traditional laboratory environments across both technical and operational dimensions. Specifically, system responsiveness, as measured by task completion times and the Application Performance Index (Apdex), was markedly improved in cloud-based settings. These results indicate that PaaS platforms can deliver more predictable and consistent computational performance, reducing latency and enhancing the overall user-perceived experience. Such improvements are particularly critical in programming education, where timely feedback and immediate execution of code are essential for reinforcing theoretical concepts and supporting active learning practices.

Cost efficiency is another notable outcome of adopting PaaS-based laboratories. The structured per-student cost model employed in this study demonstrates that operational expenses can be substantially reduced, even when accounting for subscription fees associated with PaaS services. These savings are primarily attributable to the elimination of recurring hardware and software maintenance costs, reduced energy consumption, and the minimized need for dedicated technical support. These findings are aligned with prior research highlighting the economic benefits of cloud adoption in educational settings, which underscore the feasibility of reallocating institutional resources towards pedagogical innovation and student support services (Nayar & Kumar, 2018).

Beyond the technical and economic implications, the enhanced Apdex scores observed in the cloud-based environment suggest significant pedagogical advantages. Higher user-perceived performance contributes to smoother and more engaging learning experiences, potentially increasing student motivation, satisfaction, and overall engagement in programming tasks. This aligns with prior studies emphasizing the importance of learner-centered metrics, including responsiveness, satisfaction, and interaction quality, in evaluating the effectiveness of educational technologies (Radianti et al., 2020). The integration of such user-centered evaluation measures, alongside traditional system-level benchmarks, provides a more holistic understanding of the impact of cloud-based laboratory transformations.

Furthermore, these results underscore the scalability and flexibility offered by PaaS solutions. Unlike traditional laboratories, which are constrained by physical infrastructure and resource allocation limitations, cloud-based environments allow for seamless scaling to accommodate larger student cohorts or additional courses.[1] This flexibility is particularly valuable in higher education institutions that face fluctuating enrollment or seek to implement innovative, technology-driven pedagogical models. The findings also indicate potential long-term sustainability benefits, as the reduced reliance on physical infrastructure and manual maintenance can lower the total cost of ownership (TCO) over time, supporting strategic institutional planning for future educational technology investments.

10. Conclusion and Future Work

This study empirically evaluated the transformation of traditional programming laboratories into PaaS-based environments using CloudBees. The results show that PaaS-based laboratories enhance system responsiveness, reflected in reduced task completion times and higher Apdex scores, while also lowering per-student operational costs. These findings highlight the dual benefits of PaaS adoption in higher education, combining technical improvements with economic advantages.

From a pedagogical perspective, PaaS-based laboratories offer flexible and scalable learning experiences, enabling students to engage in practical programming activities without the limitations of physical infrastructures. Integrating user-centered metrics such as perceived responsiveness and satisfaction emphasizes the importance of evaluating both technical and learner-perceived outcomes.

Limitations and Future Work:

The study is limited to a single institution, one course, and a relatively small sample size. Future research should:

1. Extend evaluations across multiple institutions and diverse academic courses.
2. Incorporate larger and more diverse student populations.
3. Integrate qualitative measures (such as interviews or focus groups) and longitudinal studies to better understand the long-term pedagogical impact of PaaS adoption on student learning outcomes.

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