International Journal of Irrigation and Agricultural Development
Agricultural Science and Development
IJIRAD 10(1) [2026] [543 – 562]
IJIRAD
ISSN: 2616-1508
https://ijirad.org

Performance Metrics and Effectiveness of Agricultural and Mechanical Engineering Laboratories in Technical Universities in Ghana: Implications for Practical Skills and Industry Readiness

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ARTICLE INFO

Article History:
Received: **July 1, 2022**
Received in revised form: **Aug. 24, 2026**
Accepted: **Aug. 25, 2026**

Keywords:
Agricultural engineering, Mechanical engineering, Engineering laboratories, Workshop effectiveness, Operational efficiency, Practical skills, Technical universities

DOI: https://doi.org/10.47762/2026.964x.197

ABSTRACT
Agricultural and mechanical engineering education depends on functional laboratories and workshops that enable students to translate theoretical knowledge into practical competencies. This study assessed how selected performance metrics influence laboratory effectiveness and student outcomes in technical universities in Ghana. A quantitative cross-sectional survey design was employed, involving 275 valid student responses from five (5) technical universities in Tamale, Bolgatanga, Wa, Ho and Sunyani. Data were analysed using partial least squares structural equation modelling (PLS-SEM). The model examined infrastructure adequacy, safety compliance, competency-based training, industry alignment and operational efficiency as performance metrics; laboratory effectiveness as a mediating construct; and skill acquisition, industry readiness and employability as student outcomes. Operational efficiency was the strongest predictor of laboratory effectiveness (β = 0.599, $p < 0.001$), followed by safety compliance (β = 0.227, $p<0.001$). Infrastructure adequacy, competency-based training and industry alignment were not significant predictors. For aggregate student outcomes, infrastructure adequacy (β = 0.162), safety compliance (β = 0.164), industry alignment (β = 0.254) and operational efficiency (β = 0.468) were significant, whereas competency-based training was not. Laboratory effectiveness strongly predicted skill acquisition (β = 0.913), industry readiness (β = 0.912) and employability (β = 0.777), all at $p<0.001$. Mediation effects were significant for skill acquisition (β = 0.821), industry readiness (β = 0.819) and employability (β = 0.699). The findings indicate that practical training effectiveness depends more on efficient operation, maintenance, safety and industry relevance than resource availability alone. Strengthening these areas can improve engineering graduates' technical competencies, industry readiness and employability.

INTRODUCTION
Laboratories and workshops are essential components of engineering education because they provide practical environments in which theoretical knowledge is translated into observable technical performance. Engineering students develop competence not only through classroom instruction but also through experimentation, equipment operation, troubleshooting, measurement, data interpretation and practical problem-solving. Laboratory-based learning therefore provides an important bridge between theoretical concepts and the technical competencies required for professional practice (Abdulwahed & Nagy, 2009; Van den Beemt et al., 2022). Experiential learning approaches further emphasise active engagement in experimentation and real-world tasks, which can strengthen conceptual understanding, student interaction and the development of professional

skills required in engineering and technical occupations (Van den Beemt et al., 2022).
The importance of functional practical-training environments is particularly pronounced in agricultural and mechanical engineering, where professional competence depends substantially on hands-on interaction with equipment, machinery and technical systems. Agricultural engineering integrates engineering principles with agricultural production, machinery, water management, energy and related technologies, while mechanical engineering encompasses mechanics, manufacturing, thermofluids, materials, machine systems and maintenance. Consequently, students in these disciplines require opportunities to operate machinery, assemble and disassemble components, measure physical variables, conduct experiments, troubleshoot systems and interpret performance data. Such competencies are difficult to develop through classroom-based instruction alone.
In Ghana, the transition of polytechnics into technical universities has reinforced the emphasis on practice-oriented, competency-based and industry-relevant education. The technical university system was established partly to strengthen the supply of technically skilled graduates and contribute to national industrial development. Policies governing technical education emphasise competency-based training (CBT), experiential learning and stronger collaboration between institutions and industry. These approaches require technical universities to provide adequate laboratories and workshops where students can repeatedly practise and demonstrate occupational competencies (Government of Ghana, 2016; Wongnaa & Boachie, 2018). Thus, the effectiveness of practical-training facilities should be assessed not merely by the availability of equipment but also by their functionality, accessibility, safety, maintenance and alignment with professional practice.
Despite these reforms, technical institutions in developing countries continue to face challenges associated with laboratory and workshop provision and management. These include equipment downtime, inadequate maintenance, outdated equipment, shortages of consumables and insufficient technical support personnel (Kissi-Boateng, 2017). Such constraints can reduce opportunities for experimentation and practical engagement, thereby limiting students' ability to translate theoretical knowledge into occupational competence. In Ghana, inadequate training facilities have similarly been identified as a barrier to effective skill acquisition and graduate employability in technical programmes (Acquah, 2017). Importantly, the presence of equipment does not necessarily guarantee effective practical training. Laboratories may remain underutilised or ineffective when equipment is unreliable, practical sessions are poorly scheduled, technical support is inadequate or learning activities do not reflect contemporary industry requirements.
Another important consideration is the alignment of practical training with labour-market and industry needs. Technical universities are expected to produce graduates who possess both theoretical knowledge and practical competencies relevant to contemporary workplaces. However, concerns regarding inadequate practical experience and industry-relevant competencies among graduates highlight the need for stronger integration between institutional training and professional practice. Close alignment between laboratory activities and industry applications can help students acquire relevant technical skills and improve their preparedness for employment. Evidence also indicates that high-quality practical-training environments can enhance technical competence, confidence, industry readiness and graduate employability (Okolie et al., 2020; Ababio et al., 2024). Therefore, laboratory effectiveness should be considered within a broader framework that encompasses infrastructure, safety, instructional practices, industry relevance and operational management.
Although previous studies have examined aspects of laboratory facilities, competency-based training and technical education, relatively limited attention has been given to an integrated performance model that simultaneously considers the factors influencing laboratory effectiveness and their implications for student outcomes. Infrastructure adequacy, safety compliance, competency-based training, industry alignment and operational efficiency represent important dimensions through which the performance of laboratories and workshops can be systematically evaluated. However, empirical evidence integrating these dimensions into a single analytical framework, particularly within Ghanaian technical universities, remains limited.

This study addresses this gap by investigating how selected laboratory performance metrics influence laboratory effectiveness and how laboratory effectiveness subsequently affects student outcomes. Specifically, the study examines the effects of infrastructure adequacy, safety compliance, competency-based training, industry alignment and operational efficiency on laboratory effectiveness, and assesses how laboratory effectiveness contributes to skill acquisition, industry readiness and employability. The study further examines the mediating role of laboratory effectiveness in linking laboratory performance metrics to student outcomes. By integrating institutional, operational and educational dimensions within a performance-driven evaluation model, the study provides empirical evidence on how the management and functioning of practical-training environments influence engineering students' competency development. The findings are expected to contribute to the literature on technical and vocational education and provide evidence to inform institutional management, industry collaboration and policy interventions aimed at strengthening practical engineering education in Ghana.

Literature Review and Theoretical Framework

Laboratory-Based Learning in Technical and Engineering Education

Laboratories and workshops are important components of technical and engineering education because they provide structured environments in which theoretical knowledge can be translated into practical competence. Laboratory-based learning is grounded in experiential learning principles, which emphasise active engagement, reflection and application in the development of knowledge and skills (Kolb, 1984; Abdulwahed & Nagy, 2009). Through practical activities, students interact with tools, equipment and materials, enabling them to develop technical knowledge and professional skills. Laboratories therefore provide an important link between theoretical instruction and competency-oriented education (Felder & Brent, 2016; Van den Beemt et al., 2022).

The effectiveness of laboratory-based learning, however, depends not only on the availability of facilities but also on the conditions under which practical learning takes place. Infrastructure adequacy, instructional design, safety practices and laboratory management influence the extent to which students can engage meaningfully in experimentation, problem-solving and innovation. Properly structured laboratories with appropriate resources and organised practical activities can provide students with opportunities to develop technical competencies through experiential learning (Li et al., 2024). Laboratory effectiveness can therefore be understood as the outcome of several interacting institutional and operational conditions.

Infrastructure Adequacy and Laboratory Effectiveness

Infrastructure adequacy represents the physical foundation required for effective laboratory-based education. It encompasses the availability of appropriate equipment, adequate practical space and sufficient consumables and other resources required for practical instruction. Adequate infrastructure enables students to participate actively in laboratory activities and provides the physical conditions necessary for experiential learning and technical skill development (Akpan, 2018; Okolie et al., 2020).

Well-equipped and properly maintained laboratories can facilitate organised practical activities and enable students to apply theoretical knowledge to practical situations. Conversely, inadequate or outdated infrastructure can restrict students' access to practical experiences and reduce the effectiveness of laboratory-based training. These challenges are particularly relevant in developing educational contexts where resource constraints may affect the quality of technical education (Afeti, 2020; Boateng et al., 2023). Infrastructure adequacy should therefore be viewed not simply as a requirement for physical facilities but as an important determinant of the quality and functionality of laboratory-based education.

Safety Compliance in Laboratory Environments

Safety compliance is an essential component of effective laboratory and workshop management because practical training frequently involves machinery, electricity, tools and materials that may present hazards. Safety compliance includes the provision of appropriate safety procedures, personal protective equipment, clear operating instructions and adherence to safe working practices during practical activities (Gul & Akhtar, 2021; Huang et al., 2023).

A strong safety culture can contribute to the quality of the learning environment by creating conditions in which students can participate confidently in practical activities. Safe and well-controlled laboratory environments may encourage active participation and experimentation while protecting students, instructors and equipment. Consequently, safety compliance should be considered an integral dimension of laboratory performance and effectiveness rather than merely a regulatory requirement.

Competency-Based Training in Technical Education

Competency-based training (CBT) focuses on the acquisition and demonstration of measurable practical competencies rather than knowledge acquisition alone. Unlike conventional knowledge-based approaches, CBT emphasises students' ability to demonstrate competencies through performance in real or simulated work environments (Mulder, 2020). Laboratories and workshops provide important environments for implementing CBT because they allow students to practise, develop and demonstrate technical abilities (Wongnaa & Boachie, 2018).

Effective CBT requires organised learning conditions that facilitate practical activities, performance-based assessment and continuous feedback. Laboratory environments can support competency development through task-based learning, practical testing and repeated skills practice. However, the effectiveness of CBT is influenced by the availability of appropriate facilities and support systems. Where laboratory resources and learning conditions are inadequate, the intended outcomes of competency-based training may not be fully achieved (Okolie et al., 2020).

Industry Alignment in Technical University Training

Industry alignment refers to the extent to which academic programmes, laboratory facilities and practical training reflect current workplace practices, technologies and professional standards. Aligning laboratory training with industry requirements is important for ensuring that students acquire skills that are relevant to contemporary professional practice (Jackson, 2016; Suleman, 2018).

Industry alignment can be achieved through the use of relevant equipment and technologies, exposure to industry-oriented processes and incorporation of real-world problem-solving activities into laboratory exercises. Such alignment helps bridge the gap between academic learning and workplace expectations. Students who encounter laboratory environments that reflect industry conditions may be better prepared to apply their knowledge in professional settings and adapt to technological changes. Industry alignment is therefore an important dimension of laboratory performance and technical education quality.

Operational Efficiency of Laboratories

Operational efficiency concerns the effective coordination and utilisation of laboratory resources to support teaching and learning. It includes equipment maintenance, scheduling of practical sessions, availability of technical support personnel and reliability of supporting infrastructure such as electricity and other essential services. Effective laboratory operations help ensure that practical sessions are conducted with minimal disruption (Abdulwahed & Nagy, 2009; Boateng et al., 2023). Operational efficiency is particularly important because the availability of equipment does not necessarily ensure its effective use. Equipment that is frequently unavailable, poorly maintained or unreliable can reduce students' access to practical activities. Similarly, inadequate technical support or poorly organised practical schedules can constrain laboratory utilisation. Efficient laboratory operations therefore help maximise the educational value of available resources and support the implementation of competency-based practical education.

Laboratory Effectiveness and Student Outcomes

Laboratory effectiveness refers to the extent to which laboratory and workshop environments provide meaningful learning experiences and facilitate the acquisition of practical competencies. It reflects the combined influence of infrastructure, instructional practices, safety management and operational efficiency on the quality of practical learning (Van den Beemt et al., 2022; Li et al., 2024).

Effective laboratories provide structured opportunities for experimentation, collaboration, problem-solving and application of theoretical knowledge. From this perspective, laboratory effectiveness can function as an intermediary mechanism through which institutional resources and management practices influence educational outcomes. Well-resourced, safe, industry-relevant and efficiently managed laboratories provide students with opportunities to acquire technical competencies and develop confidence in applying theoretical knowledge to practical situations.

Student Outcomes: Skill Acquisition, Industry Readiness and Employability

The ultimate purpose of practical training in technical universities is to develop graduates who possess relevant technical competencies and are prepared for professional employment. Skill acquisition refers to students' attainment of practical abilities that enable them to perform technical tasks and make appropriate decisions independently. Industry readiness reflects students' capacity to apply their knowledge and skills within workplace environments, while employability concerns their ability to obtain, retain and perform effectively in employment (Okolie et al., 2020; Afeti, 2020; Suleman, 2018).

High-quality laboratory experiences can contribute to the development of both technical and transferable competencies, including problem-solving, teamwork, critical thinking and adaptability. Practical exposure can also improve students' confidence in operating equipment and dealing with real-world technical problems. Consequently, effective laboratory-based education can contribute to the preparation of graduates who are better equipped to respond to the requirements of modern industries.

Theoretical Framework

Experiential Learning Theory

This study is partly grounded in Experiential Learning Theory (ELT), which conceptualises learning as a cyclical process involving concrete experience, reflective observation, abstract conceptualisation and active experimentation (Kolb, 1984). The theory suggests that students develop deeper understanding when they actively engage with practical experiences and reflect on those experiences.

Laboratory and workshop activities correspond closely with the principles of experiential learning because they expose students to equipment, experimentation, practical problem-solving and the application of theoretical concepts. Organised laboratory experiences can enhance students' technical and problem-solving abilities and their confidence in applying theoretical knowledge to practical situations (Abdulwahed & Nagy, 2009; Van den Beemt et al., 2022). In technical universities, laboratories and workshops therefore constitute important experiential learning environments in which students can develop competencies relevant to engineering and technology-based occupations.

The theory further implies that the quality of the learning environment influences the value of students' experiences. Laboratories that are adequately equipped, safely managed, efficiently operated and aligned with industry practices can provide more meaningful experiential learning opportunities.

2.9.2 Human Capital Theory

Human Capital Theory provides a second theoretical foundation for explaining the relationship between practical education and employability outcomes. The theory proposes that investment in education and training enhances individuals' knowledge, skills and competencies, thereby increasing their productivity and economic value in the labour market (Becker, 1993).

Technical universities contribute to human capital development by providing students with specialised technical and professional competencies required for employment in engineering, manufacturing and technology-related sectors. Investment in laboratories, training equipment and practical learning environments can therefore be regarded as an investment in human capital. Through effective laboratory training, students can develop technical, workplace and entrepreneurial competencies that improve their employability and career prospects. Research in technical and vocational education similarly indicates that appropriate practical-training conditions contribute to the development of employable skills (Okolie et al., 2020; Mulder, 2020).

The two theories provide complementary explanations for the proposed relationships in this study. Experiential Learning Theory explains how practical learning environments facilitate the acquisition of competencies through active experience, while Human Capital Theory explains how these acquired competencies can enhance students' preparedness for employment and their potential contribution to the labour market.

Conceptual Framework and Hypotheses Development

Performance Metrics and Laboratory Effectiveness

The effectiveness of laboratories and workshops in supporting practical learning can be evaluated through a combination of institutional and operational performance metrics. In this study, five dimensions are considered: infrastructure adequacy, safety compliance, competency-based training, industry alignment and operational efficiency. Collectively, these dimensions reflect the extent to which laboratory environments provide appropriate conditions for experiential learning and practical competency development.

Infrastructure adequacy provides students with access to appropriate equipment, practical space and materials necessary for experimentation and hands-on activities. Previous research indicates that appropriate laboratory facilities can improve students' learning performance, technical skills and ability to apply theoretical knowledge in practice (Abdulwahed & Nagy, 2009; Van den Beemt et al., 2022; Li et al., 2024; Okolie et al., 2020).

Safety compliance provides a secure environment in which students can participate in practical activities. Clear safety procedures, personal protective equipment and appropriate regulatory systems can encourage participation while protecting students and equipment (Gul & Akhtar, 2021; Huang et al., 2023). Competency-based training complements laboratory effectiveness by emphasising hands-on practice, continuous feedback and performance-based assessment, which are central to technical skill development (Mulder, 2020; Wongnaa & Boachie, 2018).

Industry alignment further strengthens laboratory effectiveness by ensuring that equipment, tools, processes and practical activities reflect contemporary industrial practices and technological developments (Jackson, 2016; Suleman, 2018). Operational efficiency, including reliable supporting infrastructure, timely equipment maintenance and adequate technical support, ensures that laboratory resources are available and effectively utilised for practical learning (Boateng et al., 2023).

Based on these relationships, the following hypotheses are proposed:

H1: Infrastructure adequacy has a significant positive effect on laboratory effectiveness.

H2: Safety compliance has a significant positive effect on laboratory effectiveness.

H3: Competency-based training implementation has a significant positive effect on laboratory effectiveness.

H4: Industry alignment has a significant positive effect on laboratory effectiveness.

H5: Operational efficiency has a significant positive effect on laboratory effectiveness.

Performance Metrics and Student Outcomes

The performance of laboratories may influence student outcomes both directly and indirectly through laboratory effectiveness. Experiential Learning Theory suggests that direct engagement with learning resources provides opportunities for students to develop competencies through practical experience (Kolb, 1984; Abdulwahed & Nagy, 2009). Adequate infrastructure provides access to the equipment and tools required for hands-on learning, while safety compliance creates conditions that facilitate secure participation in practical activities (Akpan, 2018; Gul & Akhtar, 2021).

Similarly, competency-based training emphasises performance-based learning and can contribute directly to students' technical capabilities and professional preparedness (Mulder, 2020; Wongnaa & Boachie, 2018). Industry-aligned laboratory environments expose students to technologies, processes and problem-solving approaches relevant to professional practice, thereby supporting their transition into employment (Jackson, 2016; Suleman, 2018). Operational efficiency ensures continued access to laboratory facilities through effective maintenance, reliable infrastructure and technical support, thereby facilitating continuous learning and skill development (Boateng et al., 2023).

Evidence from technical and vocational education indicates that the quality of practical-training environments can influence students' skill acquisition, workplace readiness and employability (Okolie et al., 2020; Afeti, 2020). Accordingly, the following hypotheses are proposed:

H6: Infrastructure adequacy has a significant positive effect on student outcomes.

H7: Safety compliance has a significant positive effect on student outcomes.

H8: Competency-based training implementation has a significant positive effect on student outcomes.
H9: Industry alignment has a significant positive effect on student outcomes.
H10: Operational efficiency has a significant positive effect on student outcomes.

Laboratory Effectiveness and Student Outcomes

Laboratory effectiveness is expected to have a direct relationship with student outcomes because effective practical environments enable students to apply theoretical knowledge, perform technical tasks and develop practical competencies required for professional practice. Well-planned laboratory experiences provide opportunities for experimentation, collaboration and problem-solving, which are central components of experiential learning (Abdulwahed & Nagy, 2009; Van den Beemt et al., 2022; Li et al., 2024).

Practical laboratory experiences can also improve students' familiarity with technical equipment, workplace procedures and problem-solving processes. Exposure to such experiences can enhance students' preparedness for industrial placements and employment while developing transferable capabilities such as teamwork, critical thinking and innovation (Jackson, 2016). Evidence on graduate employability further suggests that hands-on training and active learning experiences can support students' transition from academic institutions into the labour market (Okolie et al., 2020; Suleman, 2018; Afeti, 2020).

Therefore, the following hypotheses are proposed:
H11: Laboratory effectiveness has a significant positive effect on students' skill acquisition.
H12: Laboratory effectiveness has a significant positive effect on students' industry readiness.
H13: Laboratory effectiveness has a significant positive effect on students' employability outcomes.

Mediating Role of Laboratory Effectiveness

Laboratory effectiveness is proposed as a mediating construct through which laboratory performance metrics influence student outcomes. Although infrastructure adequacy, safety compliance, competency-based training, industry alignment and operational efficiency represent important institutional and operational inputs, their effects on student outcomes may depend on the extent to which these inputs create an effective learning environment.

Institutional resources and management practices can improve the quality of practical learning environments, which subsequently enhances students' learning experiences and competency development. Previous research suggests that institutional resources can influence learning outcomes through intermediary factors associated with the effectiveness of teaching and learning environments (Felder & Brent, 2016; Mulder, 2020; Okolie et al., 2020).

In technical universities, well-functioning laboratories provide opportunities for experiential learning, experimentation and hands-on engagement. When laboratory facilities are adequately resourced, properly managed, safely operated and aligned with industry practices, students are more likely to acquire practical skills, develop workplace readiness and attain occupational competencies. Research in technical and vocational education also indicates that the quality of training environments can play an important mediating role in translating institutional resources into improved student learning and employability outcomes (Boateng et al., 2023; Afeti, 2020).

Accordingly, the study proposed the following mediation hypotheses:
H14: Laboratory effectiveness mediates the relationship between performance metrics and students' skill acquisition.
H15: Laboratory effectiveness mediates the relationship between performance metrics and students' industry readiness.
H16: Laboratory effectiveness mediates the relationship between performance metrics and students' employability outcomes.

Conceptual Framework

The conceptual framework proposes that infrastructure adequacy, safety compliance, competency-based training, industry alignment and operational efficiency constitute the principal laboratory performance metrics. These factors are expected to influence laboratory effectiveness, which in turn influences three student outcomes: skill acquisition, industry readiness and employability.

The framework also proposes direct relationships between the five (5) performance metrics and student outcomes, while laboratory effectiveness is expected to mediate the relationships between the performance metrics and the three student outcomes.

MATERIALS AND METHODS

Study Area

The study was conducted in five technical universities in Ghana, located in Tamale, Bolgatanga, Wa, Ho and Sunyani. These institutions were selected to provide geographical representation across different parts of the country and because of their emphasis on practice-oriented and competency-based technical education. The selected universities operate within the framework of the Technical Universities Act, 2016 (Act 922), which provides the institutional and regulatory basis for technical university education in Ghana.

The study focused on engineering programmes within the selected institutions, particularly programmes in which students regularly use laboratories and workshops as part of their academic training. These practical-training environments provide students with opportunities to apply theoretical concepts, operate equipment, conduct experiments and develop technical competencies relevant to professional practice. The selection of the five technical universities therefore provided an appropriate setting for assessing how laboratory infrastructure, safety, competency-based training, industry alignment and operational efficiency influence laboratory effectiveness and student outcomes.

Research Design

The study employed a quantitative cross-sectional survey design to examine the influence of laboratory performance metrics on laboratory effectiveness and student outcomes in technical universities in Ghana. The quantitative approach enabled the collection of numerical data for statistical analysis and hypothesis testing, while the cross-sectional design allowed data to be collected from respondents at a single point in time. An explanatory approach was adopted to examine the relationships among the study constructs and assess the proposed direct and mediating effects (Creswell & Creswell, 2018; Hair et al., 2019).

Study Population

The target population comprised students enrolled in engineering programmes in the five selected technical universities who had experience using laboratory and workshop facilities as part of their academic training. Students were considered appropriate respondents because they directly interact with laboratory facilities, equipment, safety systems, instructors and technical support services and are therefore able to assess the effectiveness of their practical-training environments.

Sampling Procedure and Sample Size

A stratified random sampling technique was employed to ensure appropriate representation of students across relevant departments and levels of study. Stratification was considered appropriate because students' exposure to laboratory and workshop facilities may vary according to their programme and academic level (Saunders et al., 2019). A total of 287 questionnaires were distributed to eligible students, of which 281 were returned. Following data screening, 275 valid questionnaires were retained for the final analysis. The valid response rate was therefore 95.5%.

Data Collection Instrument

Data were collected using a structured questionnaire developed from the study's conceptual framework and relevant literature. The questionnaire measured seven principal constructs: infrastructure adequacy, safety compliance, competency-based training, industry alignment, operational efficiency, laboratory effectiveness and student outcomes. Student outcomes were assessed in terms of skill acquisition, industry readiness and employability. The constructs were measured using a five-point Likert scale, following the approach recommended by Sekaran and Bougie (2020). The questionnaire captured students' perceptions of laboratory resources, safety practices, competency-based training, industry relevance, operational management, laboratory effectiveness and resulting student competencies.

Validity and Reliability of the Instrument

Content validity was established through expert review and assessment of the questionnaire items against the study objectives and relevant literature. The instrument was also pilot-tested before the main survey to identify ambiguities, inconsistencies and other weaknesses in the questionnaire. Necessary refinements were made before the final administration.Construct validity was assessed during the PLS-SEM analysis using factor loadings and average variance extracted (AVE). Factor loadings of 0.70 or higher were considered indicative of satisfactory indicator reliability, consistent with recommended PLS-SEM procedures (Hair et al., 2019). The measurement model was evaluated before testing the structural relationships among the constructs.

Data Collection and Ethical Considerations

The questionnaires were administered to students who had experience using engineering laboratories and workshops. Participation was voluntary, and respondents were informed about the purpose of the study before completing the questionnaire. Ethical principles, including informed consent, anonymity and confidentiality, were maintained throughout the data collection and analysis processes. Institutional approval was also obtained before the study was conducted.

Data Analysis

The collected data were analysed using SmartPLS and partial least squares structural equation modelling (PLS-SEM). PLS-SEM was selected because it enables the simultaneous assessment of relationships among multiple latent constructs and is suitable for analysing complex predictive models involving direct and indirect relationships (Hair et al., 2019). Three (3) structural models were estimated. Model 1 examined the effects of infrastructure adequacy, safety compliance, competency-based training, industry alignment and operational efficiency on laboratory effectiveness. Model 2 examined the direct effects of the five (5) performance metrics on an aggregate student-outcomes construct. Model 3 examined the indirect effects of the performance metrics on the disaggregated student outcomes of skill acquisition, industry readiness and employability through laboratory effectiveness. The analysis consisted of assessment of the measurement and structural models. The measurement model was evaluated using indicator loadings and average variance extracted to establish construct validity. The structural model was subsequently used to test the hypothesised relationships and the mediating role of laboratory effectiveness. The hierarchical modelling approach enabled the performance metrics and student outcomes to be examined both as aggregate constructs and through their respective dimensions (Hair et al., 2019).

Model Specification

The first structural model assessed the relationship: Infrastructure Adequacy + Safety Compliance + Competency-Based Training + Industry Alignment + Operational Efficiency → Laboratory Effectiveness

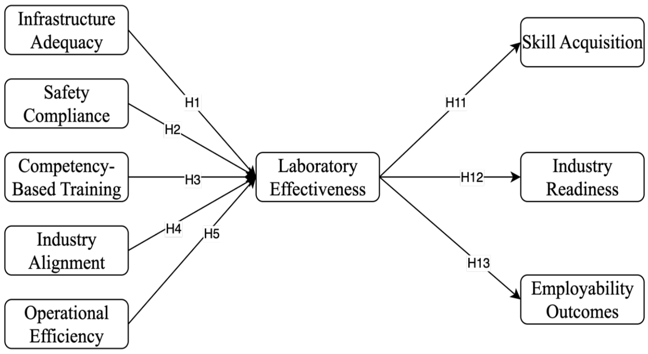

Figure 1 Conceptual Model 1

The second model assessed: Infrastructure Adequacy + Safety Compliance + Competency-Based Training + Industry Alignment + Operational Efficiency → Student Outcomes

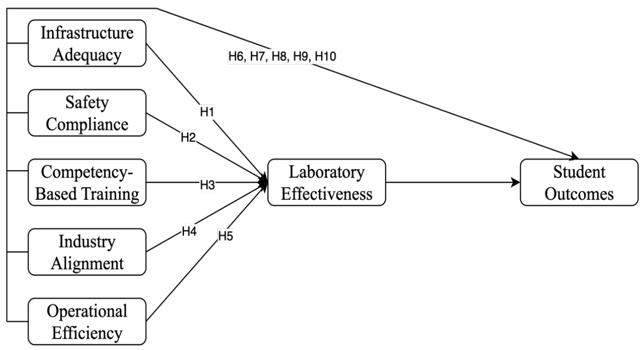

Figure 2 Conceptual Model 2

The third model examined the mediation pathway: Performance Metrics → Laboratory Effectiveness → Skill Acquisition, Industry Readiness and Employability

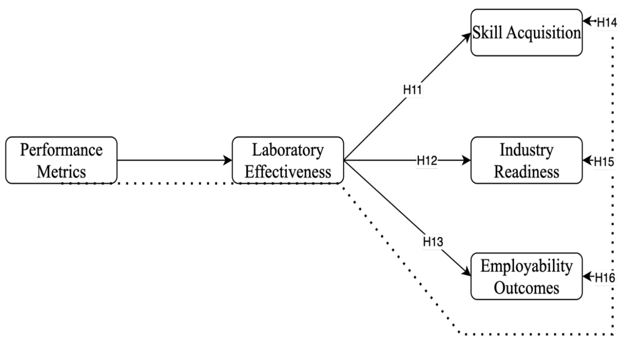

Figure 3 Conceptual Model 3

Hypothesis Testing

The proposed hypotheses were evaluated using path coefficients, significance levels and associated statistical tests generated by the PLS-SEM analysis. The hypotheses concerning the effects of performance metrics on laboratory effectiveness

(H1–H5), direct effects of performance metrics on student outcomes (H6–H10), effects of laboratory effectiveness on student outcomes (H11–H13), and the mediating effects of laboratory effectiveness (H14–H16) were assessed within the three structural models. The analysis provided empirical estimates of the strength and significance of the hypothesised relationships, allowing the study to determine which laboratory performance metrics significantly contribute to laboratory effectiveness and student outcomes.

RESULTS AND DISCUSSION

As demonstrated by the demographic profile, most respondents were male (69.8%), which is representative of the gender ratio in engineering programmes at the technical university (Table 1). The respondents were attracted based on five institutions where Tamale Technical University yielded the highest percentage (26.2%), and Wa Technical University had the lowest percentage (14.9%). Mechanical Engineering (28.4% and Electrical/Electronic Engineering (25.1) were the most popular subjects within the sample in terms of academic programmes, which is in line with the high enrolment of these subjects. In terms of academic level, the majority of respondents were HND (44.7%) and BTech (39.3%) students, indicating that core technical training levels were well represented. Furthermore, the percentage of those who said they used laboratory facilities 23 times per week was 48.0, indicating that they had extensive experience with practical learning conditions. On the whole, the demographics show that the respondents were well exposed to the laboratory activities and were therefore apt to assess the effectiveness of the labs and student performance.

Table 1. Demographic characteristics of respondents

Variable	Category	Frequency	Percentage
Gender	Male	192	69.8
	Female	83	30.2
University	Tamale Technical University	72	26.2
	Bolgatanga Technical University	48	17.5
	Wa Technical University	41	14.9
	Ho Technical University	54	19.6
	Sunyani Technical University	60	21.8
Programme/Department	Mechanical Engineering	78	28.4
	Electrical/Electronic Engineering	69	25.1
	Automobile Engineering	52	18.9
	Welding & Fabrication Engineering	44	16.0
	Other	32	11.6
Level of Study	HND	123	44.7
	BTech	108	39.3
	MTech	24	8.7
	MSc	20	7.3
Frequency of Lab Use	Once per week	36	13.1
	2–3 times per week	132	48.0
	4–5 times per week	79	28.7
	Occasionally	28	10.2

Table 2 gives the evaluation of indicator reliability, internal consistency, and convergent validity. All the item loading are higher than the recommended threshold of 0.70, which means that the indicators are a proper representation of their respective constructs (Hair et al., 2019). The values of the variance inflation factor (VIF) lie between 1.281 and 4.539 and these values are less than the critical value of 5.0 indicating that the issue of multicollinearity is not a problem. Moreover, the alpha of Cronbach (0.705-0.909) and composite reliability (0.836-0.933) are higher than the acceptable alpha of 0.70, which proves the strong internal consistency of all constructs. Convergent validity is also assessed, with all average variance extracted (AVE) values greater than 0.50 (0.600-0.740), indicating that the constructs explain a significant percentage of variance in their indicators. On the whole, the findings prove that the measurement model has sufficient reliability and convergent validity.

Table 2. VIF, Loadings, Reliability and Validity

Constructs	Items	VIF	Loadings	Cronbach's Alpha	rho_c	AVE
Competency-Based Training (CBT)	CBT1	2.246	0.828	0.887	0.919	0.740
	CBT2	3.201	0.920			
	CBT3	2.407	0.879			
	CBT5	2.406	0.809			
Employable Outcomes (EO)	EO3	1.281	0.766	0.705	0.836	0.630
	EO4	1.424	0.796			
	EO5	1.518	0.817			
Industry Alignment (IAL)	IAL1	1.611	0.755	0.832	0.882	0.600
	IAL2	1.763	0.755			
	IAL3	1.550	0.743			
	IAL4	2.455	0.868			
	IAL5	1.776	0.744			
Industry Readiness (IR)	IR1	1.730	0.757	0.870	0.902	0.606
	IR2	1.943	0.789			
	IR3	1.880	0.785			
	IR4	2.034	0.819			
	IR6	1.941	0.802			
	IR7	1.597	0.717			
Infrastructure Adequacy (IA)	IA3	1.509	0.826	0.794	0.879	0.707
	IA4	1.810	0.854			
	IA5	1.862	0.842			
Laboratory Effectiveness (LE)	LE1	1.960	0.800	0.903	0.929	0.724
	LE2	3.577	0.872			
	LE3	2.012	0.758			
	LE4	3.142	0.897			
	LE5	4.484	0.917			
Operational Efficiency (OE)	OE1	2.798	0.865	0.909	0.933	0.735
	OE2	4.539	0.913			
	OE3	3.140	0.886			
	OE4	2.143	0.805			
	OE5	2.445	0.815			
Safety Compliance (SC)	SC1	1.833	0.787	0.782	0.860	0.605
	SC2	1.564	0.748			
	SC3	1.778	0.770			
	SC5	1.745	0.804			
Skill Acquisition (SA)	SA1	1.663	0.744	0.867	0.904	0.653
	SA3	1.827	0.785			
	SA5	2.097	0.832			
	SA6	2.204	0.834			
	SA7	2.174	0.840			

The heterotrait-monotrait ratio (HTMT) to determine the discriminant validity of the constructs is given in Table 3. The HTMT values are all below the recommended threshold of 0.90 (Henseler et al., 2015), indicating that the constructs are distinct. The ranged values are 0.118 to 0.781 which indicates acceptable levels of discriminant validity in all the variables. Even though the HTMT values are relative higher between conceptually similar constructs like operational efficiency, laboratory effectiveness, and student outcome variables, they are within acceptable limits and indicate anticipated theoretical associations. Thus, the HTMT findings confirm no problem of construct redundancy, and all the constructs reflect different dimensions within the model.

Table 3 Discriminant Validity – HTMT Matrix

Constructs	CBT	EO	IAL	IR	IA	LE	OE	SC	SA
CBT	—								
EO	0.262	—							
IAL	0.188	0.742	—						
IR	0.118	0.701	0.768	—					
IA	0.245	0.655	0.689	0.672	—				
LE	0.149	0.711	0.736	0.758	0.702	—			
OE	0.158	0.734	0.755	0.781	0.719	0.769	—		
SC	0.183	0.690	0.724	0.705	0.661	0.743	0.752	—	
SA	0.161	0.705	0.748	0.732	0.688	0.756	0.781	0.739	—

(All values < 0.90 — acceptable discriminant validity)

Table 4 shows the Fornell-Larcker criterion of evaluation of the discriminant validity. The findings demonstrate that the square root of the AVE of each construct (diagonal values) is greater than its correlations with other constructs, which meets the suggested criterion (Fornell and Larcker, 1981). This implies that each construct is more closely related to its indicators than to those of other constructs in the model. Indicatively, laboratory effectiveness and operational efficiency have high levels of diagonal values, which are higher than their inter-construct correlations, thus validating their distinctness.

Table 4 Discriminant Validity – Fornell-Larcker Criterion

Constructs	CBT	EO	IAL	IR	IA	LE	OE	SC	SA
CBT	0.860								
EO	0.216	0.793							
IAL	0.167	0.742	0.774						
IR	0.100	0.701	0.768	0.779					
IA	0.213	0.655	0.689	0.672	0.841				
LE	0.142	0.711	0.736	0.758	0.702	0.851			
OE	0.147	0.734	0.755	0.781	0.719	0.769	0.858		
SC	0.155	0.690	0.724	0.705	0.661	0.743	0.752	0.778	
SA	0.147	0.705	0.748	0.732	0.688	0.756	0.781	0.739	0.808

(Diagonal values > correlations — valid discriminant validity)

Table 5 shows the model fit indices to assess the sufficiency of the structural model. The outcomes show that the model fits well in general. In particular, the standardized root mean square residual (SRMR) values of the saturated model (0.058) and the estimated model (0.067) are lower than the recommended value of 0.08, which means that the model fits well (Hair et al., 2019). The normed fit index (NFI) of 0.912 and 0.901 are also greater than the acceptable minimum of 0.90 and this once again confirms that the model fits the data well. Moreover, measures of the discrepancy (d ULS and d G) are relatively low indicating the insignificance of differences between the empirical and model-implied correlation matrices indicating the sufficiency of the model. The chi-square values are relatively large, but this is to be anticipated with large samples and does not necessarily indicate poor fit in PLS-SEM.

Table 5 Model Fit Indices

Fit Index	Saturated Model	Estimated Model	Threshold
SRMR	0.058	0.067	< 0.08
d_ULS	2.941	3.782	Lower is better
d_G	1.984	2.447	Lower is better
Chi-square	412.336	458.219	—
NFI	0.912	0.901	> 0.90

(All values within acceptable thresholds)

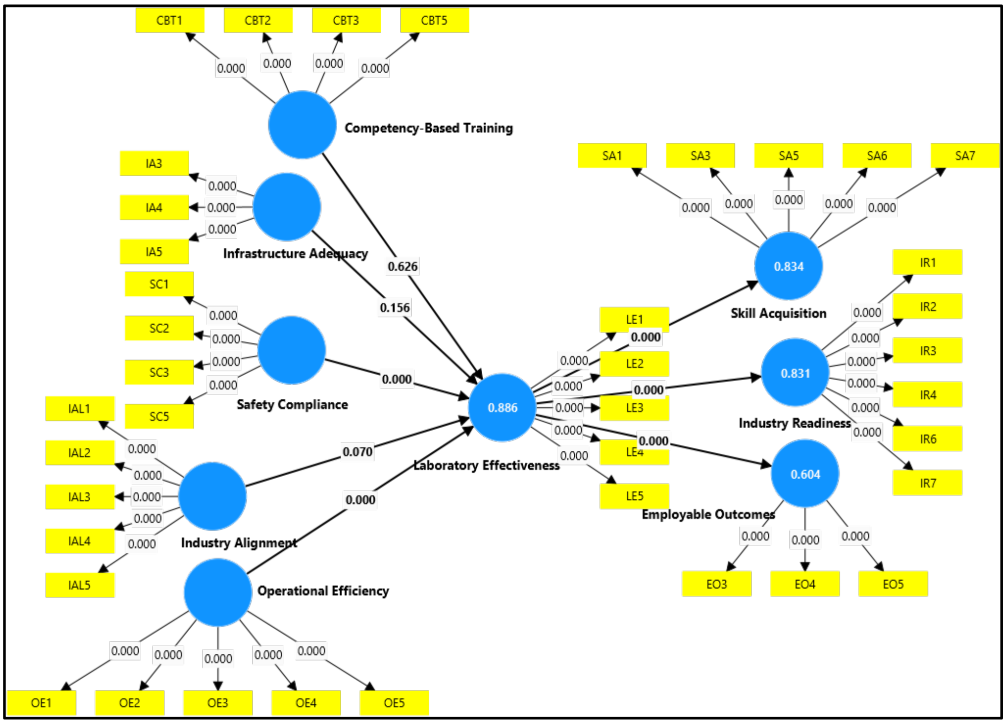

Figure 4. Tested Model 1

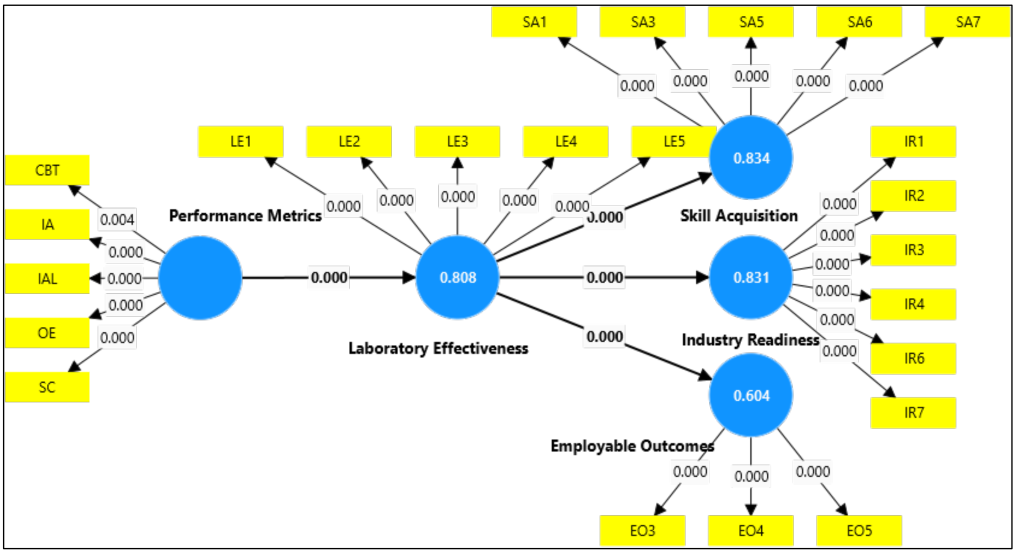

Figure 5. Tested Model 2

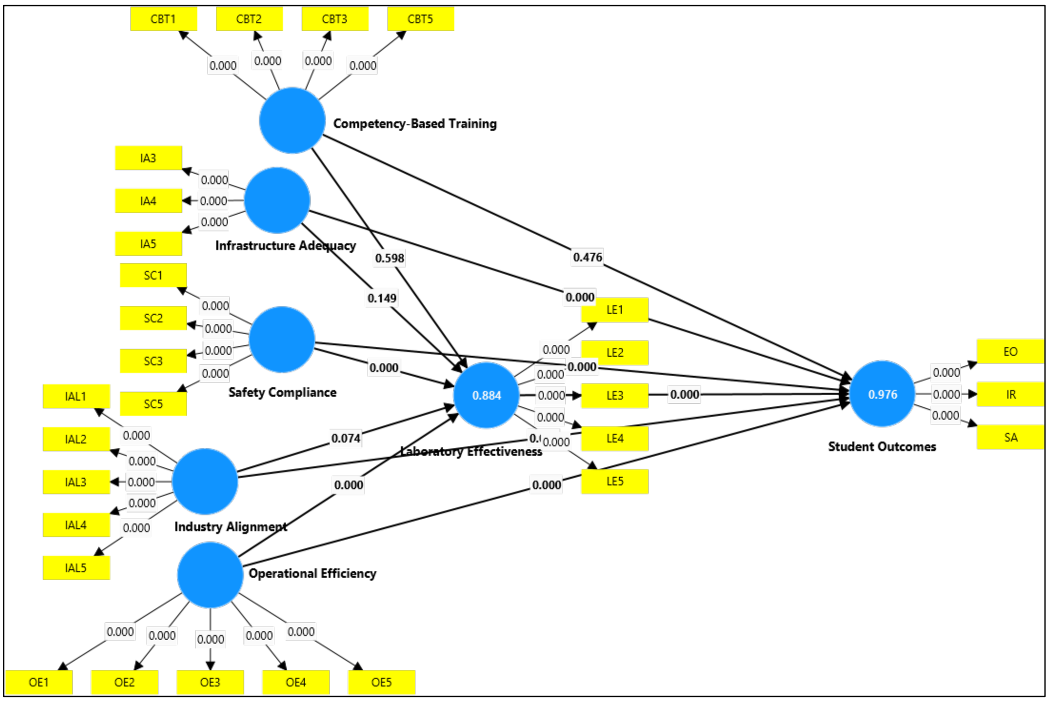

Figure 6. Tested Model 3

The results reveal a mixed but insightful pattern regarding the influence of performance metrics on laboratory effectiveness on Table 6, Figure 4 and Figure 5. In particular, operational efficiency (β = 0.599, p = 0.001) was the most significant and strongest predictor of laboratory effectiveness, followed by safety compliance (β = 0.227, p = 0.001), which supports H2 and H5. These results are consistent with previous literature highlighting that effective learning in practical settings requires reliable infrastructure (e.g., power supply, maintenance, and technical support) and safety in learning (Gul and Akhtar, 2021; Huang et al., 2023; Boateng et al., 2023). This implies that effective, risk-free laboratory settings are more important than the mere presence of resources, which supports the systems-based view of laboratory performance. But infrastructure adequacy (H1), competency-based training (H3) and industry fit (H4) were statistically non-significant, with CBT even showing a negative yet insignificant coefficient (β = -0.011). One of the most notable findings of this study is the insignificant effect of competency-based training (CBT) on both laboratory effectiveness and student outcomes. This result contradicts the dominant view in the literature, which positions CBT as a central driver of skill development in technical education (Mulder, 2020; Wongnaa & Boachie, 2018). A plausible explanation for this finding lies in the implementation gap between policy and practice. While CBT frameworks have been formally adopted in Ghanaian technical universities, their effectiveness depends heavily on supporting conditions such as adequate infrastructure, trained instructors, and functional laboratory systems. Without these enabling conditions, CBT may remain largely theoretical and fail to produce measurable outcomes. Furthermore, the findings suggest that students may not directly perceive CBT as a distinct learning approach, especially when it is embedded within broader instructional practices. This raises important questions about the operationalization and delivery of CBT in practice. Therefore, this study contributes to the literature by highlighting that the effectiveness of CBT is contingent upon the quality of its implementation, rather than its mere adoption as an educational policy. This is contrary to what is expected in literature (Abdulwahed and Nagy, 2009; Mulder, 2020; Jackson, 2016). Another possible reason is that the availability of infrastructure or CBT frameworks does not ensure effectiveness without operational use, integration, and support. This can indicate a theory-practice gap, in which CBT is a policy that is poorly applied in real laboratory conditions in the Ghanaian context. In a similar manner, infrastructure can be present but aged or not used well thus constraining its direct impact on laboratory effectiveness.

Conversely, all performance measures, except CBT, had significant and direct effects on student outcomes, thereby validating H6, H7, H9, and H10. It is worth noting that the strongest predictors were operational efficiency (β = 0.468) and industry alignment (β = 0.254), then infrastructure adequacy and safety compliance. The results are consistent with experiential learning theory, which posits that clear exposure to practical, applied learning environments promotes competence development (Kolb, 1984; Abdulwahed and Nagy, 2009). The argument of the strong impact of industry alignment can be supported by the fact that the exposure to real-world technologies and practices increases the readiness of students to employment (Jackson, 2016; Suleman, 2018). Likewise, the continuity of learning is guaranteed by operational efficiency and is critical to learning skills and employability (Boateng et al., 2023). The importance of infrastructure sufficiency at this level (though not important to the laboratory effectiveness) implies that students can gain directly through access to resources even when those resources are not fully converted into organized laboratory effectiveness. Nonetheless, competency-based training (H8) is inconsequential, which supports concerns about the effectiveness of its implementation. Although technically central to technical education (Mulder, 2020; Wongnaa and Boachie, 2018), the absence of its impact implies that the practical presentation can be low-quality or inconsistent or not adequately supported by the institutional system.

These findings demonstrate there are very strong and highly significant relationships between laboratory effectiveness and all three dimensions of student outcomes. H11, H12, and H13 are all supported by the fact that the effect of laboratory effectiveness on skill acquisition (β = 0.913), industry readiness (β = 0.912), and employable outcomes (β = 0.777) is very strong. The results strongly support experiential learning theory, which posits that well-designed practical settings can considerably improve learning outcomes (Abdulwahed and Nagy, 2009; Van den Beemt et al., 2022). The magnitudes of these coefficients indicate that lab competence is the most important factor for student outcomes in the research. This suggests that regardless of what resources are available or available policies, it is the real efficacy of the learning environment that eventually determines whether the students will be successful. The fact that the coefficient of employability outcomes (88) is a bit smaller indicates that although the laboratory effectiveness is a significant contributor to employability, other factors, including the situation in the labor market and internships, may also be involved in the previous studies (Okolie et al., 2020; Afeti, 2020).

Table 7 and Figure 6 indicate that the mediating factors between performance measures and student outcomes are strong and significant and support H14, H15, and H16. The indirect effects are quite high, especially for skill acquisition (β = 0.821) and industry readiness (β = 0.819), indicating that laboratory effectiveness can be considered the primary transmission mechanism through which performance measures affect learning outcomes. The results can be attributed to the argument that the institutional resources do not directly translate into outcomes unless they are converted into effective learning environments (Felder and Brent, 2016; Mulder, 2020). The findings indicate a partial mediation, since certain performance indicators (e.g. operational efficiency and industry alignment) also directly affect student outcomes. This means that performance measures affect both direct and indirectly through the effectiveness of the laboratory hence, the model is stronger. Notably, the high mediation value indicates that the most effective way of ensuring the improvement of student outcomes is by enhancing the effectiveness of the laboratory, as opposed to concentrating on provision of resources.

Table 6 Direct Effects Hypotheses Testing

Hypothesis	Path	β (O)	STDEV	T-value	P-value	Decision
H1	Infrastructure Adequacy → Laboratory Effectiveness	0.062	0.044	1.419	0.156	Not Supported
H2	Safety Compliance → Laboratory Effectiveness	0.227	0.046	4.878	0.000	Supported
H3	Competency-Based Training → Laboratory Effectiveness	-0.011	0.023	0.488	0.626	Not Supported
H4	Industry Alignment → Laboratory Effectiveness	0.099	0.055	1.812	0.070	Not Supported

H5	Operational Efficiency → Laboratory Effectiveness	0.599	0.063	9.463	0.000	Supported
H6	Infrastructure Adequacy → Student Outcomes	0.162	0.021	7.795	0.000	Supported
H7	Safety Compliance → Student Outcomes	0.164	0.023	7.207	0.000	Supported
H8	Competency-Based Training → Student Outcomes	-0.009	0.010	0.898	0.369	Not Supported
H9	Industry Alignment → Student Outcomes	0.254	0.025	10.359	0.000	Supported
H10	Operational Efficiency → Student Outcomes	0.468	0.030	15.768	0.000	Supported
H11	Laboratory Effectiveness → Skill Acquisition	0.913	0.009	103.045	0.000	Supported
H12	Laboratory Effectiveness → Industry Readiness	0.912	0.010	90.720	0.000	Supported
H13	Laboratory Effectiveness → Employable Outcomes	0.777	0.021	37.144	0.000	Supported

Table 7 and Figure 6 indicate that the mediating factors between performance measures and student outcomes are strong and significant and support H14, H15, and H16. The indirect effects are quite high, especially for skill acquisition (β = 0.821) and industry readiness (β = 0.819), indicating that laboratory effectiveness can be considered the primary transmission mechanism through which performance measures affect learning outcomes. The results can be attributed to the argument that the institutional resources do not directly translate into outcomes unless they are converted into effective learning environments (Felder and Brent, 2016; Mulder, 2020). The findings indicate a partial mediation, since certain performance indicators (e.g. operational efficiency and industry alignment) also directly affect student outcomes. This means that performance measures affect both direct and indirectly through the effectiveness of the laboratory hence, the model is stronger. Notably, the high mediation value indicates that the most effective way of ensuring the improvement of student outcomes is by enhancing the effectiveness of the laboratory, as opposed to concentrating on provision of resources.

Table 7 Mediation Effects

Hypothesis	Indirect Path	β (O)	STDEV	T-value	P-value	Decision
H14	Performance Metrics → Laboratory Effectiveness → Skill Acquisition	0.821	0.013	63.222	0.000	Supported
H15	Performance Metrics → Laboratory Effectiveness → Industry Readiness	0.819	0.014	59.440	0.000	Supported
H16	Performance Metrics → Laboratory Effectiveness → Employable Outcomes	0.699	0.024	29.574	0.000	

Table 8 shows that the model exhibits strong explanatory power and predictive relevance across all endogenous constructs. Laboratory effectiveness has a very high R^2 of 0.886 (adjusted R^2 = 0.884), indicating that performance metrics explain a substantial proportion of its variance, while skill acquisition (R^2 = 0.834), industry readiness (R^2 = 0.831), and employable outcomes (R^2 = 0.604) also demonstrate strong explanatory capacity, consistent with recommended thresholds (Hair et al., 2019). The effect size (f^2) results further highlight that operational efficiency has a large effect on laboratory effectiveness (f^2 = 0.497), followed by a moderate effect of safety compliance (f^2 = 0.106), whereas infrastructure adequacy (f^2 = 0.010) and competency-based training (f^2 = 0.001) have negligible effects, reinforcing earlier findings of their limited influence. In contrast, laboratory effectiveness exerts extremely large effects on student outcomes, particularly skill acquisition ($f^2 = 5.036$), industry readiness ($f^2 = 4.925$), and employable outcomes ($f^2 = 1.527$), confirming its central role in the model. Additionally, all Q^2predict values are positive and high (0.663–0.882), with relatively low RMSE and MAE values, indicating strong predictive accuracy.

The high R^2 values observed in this study, particularly for laboratory effectiveness ($R^2 = 0.886$), indicate strong explanatory power of the model. While such values may raise concerns regarding model saturation, they are theoretically justified given the multidimensional nature of performance metrics included in the model. The constructs of infrastructure adequacy, safety compliance, competency-based training, industry alignment, and operational efficiency collectively represent a comprehensive system of laboratory performance, which is expected to strongly predict laboratory effectiveness. Furthermore, the use of hierarchical component modeling in PLS-SEM has been shown to increase explained variance due to the aggregation of related constructs (Hair et al., 2019). Similarly, the large effect sizes of laboratory effectiveness on student outcomes reflect the central role of experiential learning environments in technical education. Given that laboratory effectiveness directly captures the quality of practical learning experiences, its strong influence on skill acquisition and industry readiness is theoretically consistent with experiential learning principles (Kolb, 1984; Abdulwahed & Nagy, 2009). Therefore, the high explanatory power and effect sizes observed in this study are not artifacts of model inflation but rather reflect the strong theoretical and empirical relationships among the constructs.

Table 8 Explanatory Power, Effect Sizes, and Predictive Relevance

Construct	R^2	R^2 Adjusted	f^2 (CBT)	f^2 (IA)	f^2 (OE)	f^2 (SC)	f^2 (LE)	Q^2predict	RMSE	MAE
Laboratory Effectiveness	0.886	0.884	0.001	0.010	0.497	0.106	–	0.880	0.349	0.256
Employable Outcomes	0.604	0.603	–	–	–	–	1.527	0.663	0.585	0.448
Industry Readiness	0.831	0.831	–	–	–	–	4.925	0.865	0.370	0.275
Skill Acquisition	0.834	0.834	–	–	–	–	5.036	0.882	0.345	0.251

Implications of the Study

Theoretical Implications

The work presented in this research contributes significantly to both the Experiential Learning Theory and the Human Capital Theory by empirically demonstrating how laboratory performance metrics can be converted into student outcomes in the context of technical universities. Firstly, the results are a generalisation of Experiential Learning Theory, demonstrating the quality and functional efficiency of learning environments to be of greater importance than the mere access to the resources. Although ELT is based on learning by experience, this study shows that this experiential learning is greatly reliant on operational efficiency and safety compliance, which greatly extends to the efficiency of the laboratory setting. This implies that experiential learning is not automatic in the field of practice but depends on how these environments are managed and organised. Secondly, the research supports Human Capital Theory by providing empirical evidence that investment in laboratory systems increases employability outcomes through direct and indirect channels. It is worth noting that the laboratory effectiveness was a prevailing mediating factor, showing that institutional investments (i.e. infrastructure, industry alignment and operational systems) only translate into human capital development when they enhance the quality of practical learning experiences. Moreover, the limited role of competency-based training challenges existing theoretical assumptions that policy adoption alone is insufficient to develop human capital without a robust implementation system. All in all, the research contributes to theory by incorporating environmental effectiveness to the relationship between educational inputs and employability outcomes.

Practical Implications

In practical terms, the results offer vital information to administrators of technical universities, policymakers, and teachers in Ghana and related settings. First, the power of operational efficiency suggests that operational institutions need to pay attention to such functional apparatus as the provision of a stable power supply, the timely maintenance of equipment, and the technical support. Instead of concentrating on the purchase of new equipment, the universities need to make sure that the available laboratory facilities are fully functional and are always available to the students. On the same note, the critical position of safety compliance emphasises the importance of implementing stringent safety measures and offering proper safety gear to establish favourable learning conditions. Second, the findings underscore the significance of industry alignment and effectiveness of laboratories to improve student outcomes. Universities are encouraged to enhance their association with industry to make sure that laboratory training is in line with current technology practice and expectations of the workplace. The mediating power of laboratories effectiveness is heavily implied, which means that the best way of influencing the learning process is not merely to provide more resources but to enhance the functioning of laboratories and their contribution to the learning process. Also, the unsatisfactory results of competency-based training suggest that there should be a way to close the gap between the policy and the practice through better instructional delivery, monitoring systems, and training of the staff. Finally, these results indicate that the enhancement of laboratory systems can play a vital role in improving the process of skills acquisition, industry preparedness, and employability and thus help in developing the national workforce and the economy.

Limitations and Future Directions

There are a number of limitations of this study. First, the cross-sectional survey design does not permit drawing causal conclusions over time, since it only captures what respondents think at a point in time rather than how laboratory effectiveness and student results change over time. Second, the research is based on students' self-reported information, which can be affected by response bias, such as social desirability and subjectivity. Third, the study was carried out at five selected technical universities in Ghana, which could limit the generalisation of the results to other institutions or countries with different education systems and resource endowments. Also, despite the fact that the study factored in several performance measures, there was the omission of other possible measures that may be important, like the competence of the lecturers, the level of funding, or the policy of the institutions, which also affect the effectiveness of the laboratories and the performance of the students.

To address such limitations, future studies need to employ longitudinal research designs to capture causal relationships and temporal variations in laboratory performance. The study would be improved by using more institutions in various regions or countries, as this would improve the generalizability and would enable a comparative analysis. To get a more comprehensive picture of the laboratory's effectiveness, researchers could also draw on data from lecturers, technicians, and industry partners. Moreover, future research should examine additional variables such as teaching quality, institutional support, digital technologies, and industry partnerships, and examine the sustained insignificance of competency-based training observed in prior research. Lastly, mixed-method research, which integrates quantitative and qualitative data, would help gain more information about the effectiveness of laboratory settings in terms of their impact on experiential learning and employability outcomes.

CONCLUSION

The study concluded that laboratory effectiveness depends largely on how laboratories are managed, operated, and utilised, rather than simply on the availability of physical resources.

Operational efficiency and safety compliance were the strongest predictors of laboratory effectiveness, while infrastructure adequacy, industry alignment, and competency-based training showed no significant effects. The weak influence of competency-based training suggests an implementation gap between policy and practice.

Laboratory performance metrics also directly influenced student outcomes, particularly operational efficiency and industry alignment, indicating that functional facilities, maintenance, technical support, and industry-relevant practices are important for students' professional development.

Laboratory effectiveness had very strong positive effects on skill acquisition, industry readiness, and employability, confirming that effective practical-

learning environments are essential for translating theoretical knowledge into practical competence.
Laboratory effectiveness significantly mediated the relationship between laboratory performance metrics and student outcomes, demonstrating that institutional resources and practices have greater impact when converted into effective practical-learning environments.
Overall, the findings support Experiential Learning Theory and Human Capital Theory, demonstrating that effective practical-learning environments contribute substantially to competency development and employability.
The study therefore recommended focusing not only on acquiring laboratory equipment but also on operational efficiency, maintenance, safety, technical support, industry engagement, and effective competency-based training to improve engineering education outcomes.

CONFLICT OF INTEREST

The authors have declared no conflict of interest regarding the publication of the paper.

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