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Research Paper

Examining the Impact of Laboratory Resource Constraints on Botany Students' Practical Learning Outcomes in Islamia University of Bahawalpur, Pakistan: Does Self-Efficacy and Instructor Support Matter?

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Abstract

This research has far-reaching implications due to the expansive groups of key stakeholders involved with laboratory-based instruction: educators, heads of departments, and decision-makers who allocate resources toward improving laboratory-based instruction. Once we have a sense how resources, or their absence, impacts outcomes, then institutions can tackle improvements to the laboratory that are more likely focused. Further, the identification of self-efficacy provided faculty with the justification for developing interventions that may improve students' confidence when conducting experiments. Additionally, the moderating role of instructor support reinforces the importance of pedagogies that enable students to engage with subsequent directed instruction, timely feedback, and personal mentorship. Islamia University of Bahawalpur utilized this study as a means for joining qualitative studies with quantitative studies, and analyzing barriers and facilitators to effective learning in the laboratory. Ultimately, the research findings can and were used as foundational evidence based decision making to enhance science education and students' performance, and hopefully support the development of practical skills shared within in a discipline such as botany or other lab-based disciplines. The study also contributes some theoretical implications related to the influence of cognitive, environmental, and instructional variables and recommendations for improving laboratory education and practice in botany.

Introduction

The increasing emphasis on applied and competency-based learning in higher education has brought attention to the importance of laboratory contexts in scientific disciplines such as botany. Universities in space-constrained or developing countries such as Pakistan (Schmidgen, 2021), which offer laboratory-based science education, have positive and constructive benefits for student development in scientific inquiry, practical skills, and conceptual understanding. Within the context of the Islamia University of Bahawalpur, laboratory courses in botany provide students with most or all of their initial exposure to experimental methods, plant specimens, analytical skills, and research experiences (Haq, 2021). However, on most occasions, institutions experience difficulties sustaining complete, modern laboratory facilities that align with present-day pedagogical practices (Severo et al., 2025). As student numbers increase and demand for experiential learning rises, the adequacy of the laboratory's physical infrastructure, availability of equipment, and the condensing quality of support and instruction becomes essential considerations for positive learning outcomes (Goff et al., 2011). As a result, there is an opportunity to examine how laboratory conditions influence students' performance and confidence to learn, in situations and spaces where laboratory funding and resources may not be available.

Experiential learning outcomes in botany programs are related to the quality of the laboratory environment and accessibility. Students may not develop proficiency in laboratory skills when laboratories are poorly equipped, compact, or have older equipment (Oluwasegun & Oluwaseun, 2023). Students may not achieve the theoretical understanding, or apply experimental skills accurately, and this may result in lower student performance. Students may believe that they are not prepared for a second course, or practice, regulated by demands that included demonstrated theoretical understandings that could be translated into practical skills (Uno, 2009). Islamia University of Bahawalpur was concerned with these practicalities for the faculty and administrators responsible for maintaining standards. Therefore, the dependent variable to be studied, laboratory learning outcomes, is dependent on practical challenges associated with laboratory learning and can include limited

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equipment, limited reagents, overcrowded (or poorly maintained) spaces (Miller, Newman, & Kotuby-Amacher, 1997). These issues can completely undermine if and how students apply a demonstrated theoretical understanding of conditions to practical implementation, which is why it's important to study elements of laboratory learning outcome performance.

Although these issues are becoming increasingly recognized, theoretical and empirical gaps still exist in understanding how environmental and psychological factors interact to produce laboratory learning outcomes. Previous studies considered self-efficacy in relation to academic performance, but there is limited empirical evidence on the impact of laboratory resource limitations on students' self-efficacy in undertaking experimental work (Bizimana, 2022; Byukusenge, Nsanganwimana, & Tarmo, 2024). Furthermore, research has rarely investigated whether instructor support might mitigate the negative effects of resource limitations, or whether it acts to strengthen the relationship between self-efficacy and performance. Existing literature tends to study educational outcomes in higher education academic environments rather than in individualized disciplines and laboratory contexts, and even fewer authors study the above topics in relation to higher education in Pakistan (Dávila et al., 2021; Klimenko et al., 2023). The result is an underdeveloped literature base, with few or no models developed that consider resource limitations, self-beliefs and instructor support in explaining laboratory learning outcomes with botany students (Jamil et al., 2018). Theoretical gaps highlighted above emphasize the need for a more holistic and contextualized approach to examining student learning in practical situations in laboratory-based programs.

This study seeks to address these gaps by assessing how laboratory resource constraints, students' laboratory self-efficacy, and instructor support collectively impact laboratory learning outcomes in botany students at the Islamia University of Bahawalpur (Lee et al., 2020). The study investigates whether the experience of resource constraints has an explanatory effect on laboratory learning outcomes, whether self-efficacy serves as a mediation mechanism, and whether instructor support moderates these effects (Beck & Blumer, 2021). The aim of our study is to provide an even better understanding of how contextual-environmental factors and psychological factors interact to inform students' laboratory performance; to achieve this aim, we included these variables within a single conceptual model. The study also provided a contribution to contextual knowledge by providing empirical evidence for university laboratory contexts in a developing country, thereby adding to previous identified findings in the literature that are more general in nature and largely devoid of context (Chiang et al., 2021). Finally, the contribution of this study includes a model framework that provides an explanation of laboratory learning outcomes, while also scaffolding points of actionability for intervention in laboratory contexts and pedagogies.

The implications of this study reflect a wide range of key stakeholders that are directly related to lab-based instruction: instructors, departments heads, and decision-makers who provide (or do not provide) resources needed to improve lab-based instruction. When we understand how these resources, or lack of, affect student learning, then institutions can address lab improvement that is actionable and more likely to be purposeful. Identifying self-efficacy in one aspect of lab based instruction gives faculty the authority to develop interventions to increase students' self-efficacy, and ultimately confidence, to conduct experiments (Muneer et al., 2021). Furthermore, the instructor support moderator highlights the importance of pedagogy that provides students with guidance, on-time feedback, and personal mentoring support (Gill, Khan, & Akram, 2025). Islamia University of Bahawalpur used this study to encompass the qualitative and quantitative studies and examine barriers and facilitators for effective laboratory learning (Amanat, Kanwal, & Akhter, 2024). Finally, it is expected that the study outcomes helped facilitate an evidence-based decision-making approach that improved science education and student engagement and likely also strengthened practical skill acquisition in a specific discipline like botany or any other lab-based discipline.

Literature Review

Theoretical Foundation

Social Cognitive Theory (SCT) offers a solid framework for examining how personal, environmental, and behavioral characteristics interact to affect student learning outcomes. In SCT, individuals' beliefs in their own capabilities—self-efficacy—are emphasized as an important factor influencing how students approach tasks, how they persevere (or give up) when faced with difficulty, and how they respond, react, or accept contextual constraints, etc. In this study, environmental characteristics such as lacking laboratory resources, lessen students' capacity to engage meaningfully in practical work (Gya & Bjune, 2021). If laboratory work is inappropriate due to laboratory resource constraints (e.g., equipment, space, materials), students' self-efficacy beliefs become reduced and we know from SCT that these beliefs are likely to have an adverse effect on students' learning outcomes. SCT also emphasizes the importance of social support when determining learning behaviors. Instructor support and guidance are a type of social influence that can lessen the impacts of limited resources through provision of reassurance, guidance and assistance with problem-solving (Stagg & Donkin, 2013). The value of social support may increase students' self-efficacy, which may ultimately result in greater performance despite challenges in the environment. The pedagogical model, grounded in social cognitive theory and proposed here, purports to explain both direct and indirect effects of laboratory constraints, which is contingent on self-efficacy as a mediator, and acknowledge the moderator of instructor support as an important resource to strengthen students' learning experiences (Colon et al., 2020).

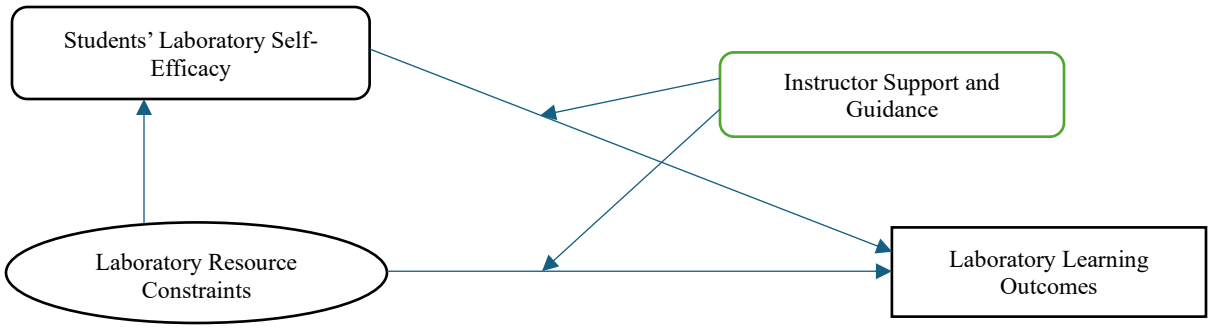

Figure 1: Framework of the Study.

Hypotheses Development

Laboratory Resource Constraints and Laboratory Learning Outcomes

The restriction of resources in a laboratory environment is often a critical environmental variable that can very significantly affect the ability of students to reach their laboratory learning outcomes. When laboratory resources are less than fully funded and/or in poor working order (e.g., equipment, tools, chemicals both biologically necessary and not, and other instructional materials in the curriculum), students face limitations on their hands-on investigative engagement and level of active engagement (Loveys & Riggs, 2019). Having limited functional equipment means that students have fewer opportunities for repetition and practice, lengthy wait times, and fewer active learning experiences, which can limit the development of their practical skills and attitudes. Learning in underdeveloped laboratory conditions can create a learning experience that is frustrating, demotivating, and confidence-shaking while performing experiments (Schnell et al., 2021). These environments ultimately restrict students' abilities to transfer theory into practical competency and impact learning performance overall. Experiential learning is fundamentally predicated on lab learning outcomes where students learn through practice, observation, and interaction with scientific equipment. When there are resource constraints, the depth and accuracy of the learning experience diminishes (Shotemirovna, 2025). Resource constraints may also hinder the instructor's ability to plausibly demonstrate procedures or oversee students efficiently, which can create inequities in the learning experience (Dean, Muriithi, & Culley, 2020). For these reasons, we contended that resource constraints could have a considerable influence over students' practical learning outcomes, and this provided the basis for a first hypothesis: that a relationship exists between students' perceptions of laboratory resource constraints and their laboratory learning outcomes.

Hypothesis 1: *There is a relationship between laboratory resource constraints and laboratory learning outcomes.*

Mediating role of Students' Laboratory Self-Efficacy between Laboratory Resource Constraints and Laboratory Learning Outcomes

Students' potential to effectively engage in practical learning experiences in laboratory contexts relates to the laboratory resources they have access to, as well as their skills. Inadequate laboratory resources such as equipment, materials, and workspaces may impede students' ability to perform an experiment independently or with confidence because of these constraints, which can also lead to students' self-perception about their competence in doing laboratory tasks (Kolil, Muthupalani, & Achuthan, 2020). Therefore, it is important to consider laboratory resource constraints as an environmental factor related to students' laboratory self-efficacy. When students perform work in well-resourced settings, students were more likely to feel capable, motivated, and prepared; however, in resourced-limited settings, students' confidence may deteriorate because they cannot practice, further investigate, or explore the concepts completely (Çelik, Pektas, & Karamustafaoglu, 2021). Thus, the provision of resources demonstrates a crucial dimension of students' beliefs about their ability to effectively perform laboratory tasks, asserting that laboratory accessibility is fundamentally related with all dimensions of student's laboratory self-efficacy.

Student self-efficacy in the lab directly influences student outcomes in the lab. Students with high self-efficacy tried a challenging technique, continue after making a mistake, and are more likely to employ deep learning while completing tasks in the lab (Dyrberg, Treusch, & Wiegand, 2017). These outcomes resulted in better conceptual understanding, technical capabilities, and lab performance overall. Students with high self-efficacy demonstrate more curiosity, engagement, persistence, and problem-solving skills. These traits lead to better outcomes in the laboratory learning process. Conversely, students with low self-efficacy typically avoid tasks, engage minimally, or rely on their teachers as the first option, resulting in poorer learning outcomes (Moss et al., 2018).

In line with the aforementioned relationships, it is assumed that students' laboratory self-efficacy would mediate the association between laboratory resources constraints and laboratory learning outcomes (Vydra & Kováčik, 2025). Resource constraints typically do not directly diminish learning outcomes; instead, resource constraints first diminish students' beliefs in their capabilities (Eymur, 2018). When resource constraints diminish students' confidence, they also likely become disengaged, less persistent, and perform at lower levels. When enough resources contribute to self-efficacy,

individuals were persist and attained higher actions/goal states even in moderate forms of challenge. Thus, self-efficacy can be understood as a psychological process for how environmental constraints are expressed as differences in learning performance, leading to its mediational role in this relationship.

Hypothesis 2: *There is a relationship between laboratory resource constraints and students' laboratory self-efficacy.*

Hypothesis 3: *There is a relationship between students' laboratory self-efficacy and laboratory learning outcomes.*

Hypothesis 4: *Students' laboratory self-efficacy mediates the relationship between laboratory resource constraints and laboratory learning outcomes.*

Moderating role of Instructor Support and Guidance

Instructor guidance and support should be acknowledged because they can affect students response to the challenge presented in lab contexts—for example, learning experiences based on limited out-dated equipment, limited provision of materials or limited space. In general, when faced with challenges when accessing limited resources (whether in the laboratory or otherwise), students often don't fully engage these quasi-experiential learning contexts, central to learner engagement, progressive inquiry, learning, and developing their scientific literacy (Ajizah et al., 2024). Instructor support lessened the impact of limited resources by optimizing and modifying the students learning experience, in relation to greater engagement, through providing options, clear rationales for adaptations and if necessary, appropriate resources in support of problem based learning. Educators who offer structured guidance, timely feedback, and emotional support enable students to have confidence and stay motivated despite limits presented by resources. Having educators in the learning environment provided students the ability to overcome limitations more effectively leading to less impact on learning outcomes (Krosnick & Moore, 2025). Thus, educator support or guidance was able to moderate the relationship between laboratory resource limits and laboratory learning outcomes, decreasing the negative impact of resource limits.

Similarly, instructor support is an important factor for enhancing students' connections between laboratory self-efficacy and learning outcomes. Students may have confidence in their laboratory skills, but instructor supportive feedback afforded students to more fully apply their self-efficacy into learning behaviors (Ali & Arif, 2019). instructor support allows students to apply their skills, improve their skills, and navigate the challenges they encounter with a task, contributing to the positive relationship of self-efficacy with their learning outcomes (Sindelar & Witkowski, 2021). In some instances, in settings where there is little guidance available, even students with high levels of self-efficacy may not perform optimally as a result of lack of direction or feedback. As instructor support and guidance are expected to be moderating the relationships between self-efficacy in the laboratory, we expect the association self-efficacy and student performance outputs to be stronger when there is guidance and or students aware of the availability of support.

Hypothesis 5: *Instructor support and guidance moderate the relationship between laboratory resource constraints and laboratory learning outcomes.*

Hypothesis 6: *Instructor support and guidance moderate the relationship between students' laboratory self-efficacy and laboratory learning outcomes.*

Methodology

Research Design

Utilizing a quantitative, cross-sectional research design, this research seeks to explore the relationships among laboratory resource constraints, students' laboratory self-efficacy, instructor support and guidance, and laboratory learning outcomes in the domain of financial institutions' training laboratories in Pakistan. A quantitative design is appropriate in this study context as the study does serve to test theorized hypotheses, while also measuring the strength and direction of the relationships among the constructs clearly defined. Data were obtained through a structured self-administered questionnaire, which was developed to capture respondents' perceptions of their experiences in the laboratory, resource availability, self-efficacy, instructor support, and outcomes of learning. All measurement items were adapted from existing scales and were measured using a five-point Likert response format for consistency and easier interpretation.

The designated population is made up of trainees and employees who participate in laboratory-based training programs offered by financial institutions around Pakistan. Non-probability purposive sampling was applied, as individuals who were currently participating in laboratory-based learning environments were of highest relevance to the research aim. The sample size adhered to recommendations for partial least squares structural equation modeling and ensured adequate statistical power to test the model. The analysis of the data was performed using Smart PLS so that the measurement model and structural model could be assessed simultaneously. Prior to hypothesis testing, reliability, validity, and the potential for common method bias were assessed. That means we have carefully designed the research in a way that maintains methodological rigor and allows for solid testing of both a direct and a moderated–mediated relationship in the conceptual model.

Population and Sampling

The population for this study includes students enrolled in laboratory courses at post-secondary educational institutions (higher education) that are at least partially in science, engineering, or technical courses that incorporate some form of required practical laboratory activity as part of the designed curriculum. These students are an appropriate unit of analysis because they use laboratory resources (e.g., chemicals, equipment, and technology) regularly, are supported by instructors, and they are affected by laboratory experiences that demonstrate their self-efficacy in learning. The research

encompasses undergraduate and postgraduate students who have completed at least one laboratory course over the academic semester based on the goals of this study to ensure that students have had enough exposure to the laboratory environment to be able to accurately assess the challenges and strategies available to them.

A sampling approach was employed to ensure that the sampled participants adequately represented the characteristics of the wider student body. The sampling approach used non-probability purposive sampling, and only involved students who are directly active in the lab activities because they are in an informed position to provide useful information about learning experiences and limitations associated with resources. The sample size was determined following the guidelines suggested for structural equation modeling, which often recommends a minimum of 10 responses per indicator. This rule of thumb suggested that the final sample was just over ___ respondents and sufficient to test the model and hypotheses. Data collection occurred at multiple institutions to assist with generalizability and capture to diversity across laboratory resources, teaching practices, and student perceptions.

Questionnaire Development

Table 1 highlighted the variable measures of Laboratory Resource Constraints, Laboratory Self-Efficacy, Instructor Support and Laboratory Learning Outcomes. Laboratory Resource Constraints was measured through four scale items. Furthermore, Laboratory Self-Efficacy was measured through four scale items. Instructor Support was measured through four scale items, and Laboratory Learning Outcomes was measured through four scale items.

In order to establish the quality and appropriateness of the research instrument, a pilot study was conducted in two phases: expert review and small-sample reliability testing. At first, three researchers with education and laboratory research content expertise examined the questionnaire items. Each item was scrutinized for clarity, relevance, representativeness, and construct. The expert review focused on refining ambiguous wording, checking each statement for its intended dimension accuracy, and ensuring that each response scale corresponded to the actual conditions working in the lab. Based on the reviewers' recommendations, minor edits were made in the area of item clarity and contextual relevance regarding being limited by the lab or instructor . Further, the expert validation review was conducted to build on the initial content validation by confirming that every item addressed the constructs without redundancy and minimal overlap.

After undergoing expert review, the revised instrument was administered to a small pilot sample that mirrored the target population. My group used data collected from a pilot group to assess internal consistency reliability applying standard reliability statistics (Cronbach's alpha). The reliability statistics revealed strong internal consistency across the scales showing that the items within each construct consistently operationalize a single construct. Alpha values for Laboratory Resource Constraints, Laboratory Self-Efficacy, Instructor Support, and Laboratory Learning Outcomes were above the acceptable method which confirms the trustworthiness and reliability of the items developed. Reliability values in this study suggested participants had the same understanding about the items and the constructs were accurately gauged overall. The pilot study confirmed the instrument to be valid, reliable, and appropriate for large scale data collection.

Table 1: Scale Items**.**

Variable	Scale Items (Likert)	Scale Source
Laboratory Resource Constraints	The laboratory lacks sufficient equipment for conducting experiments. Chemicals and reagents are often unavailable or insufficient. Lab space and facilities are inadequate for proper practical work. Outdated or malfunctioning instruments make it difficult to complete experiments.	Developed for this study
Laboratory Self-Efficacy	I feel confident in performing botanical experiments independently. I can accurately handle lab instruments and materials. I am capable of following experimental procedures correctly. I believe I can successfully complete laboratory assignments.	Developed for this study
Instructor Support	My instructors provide clear instructions during lab sessions. I receive helpful feedback on my laboratory work. My instructors are available to assist when I face difficulties in the lab. I feel supported by instructors in improving my practical skills.	Developed for this study
Laboratory Learning Outcomes	I am able to achieve accurate results in botanical experiments. I understand key botanical concepts through lab work. My practical skills have improved due to laboratory practice. I can apply laboratory techniques effectively in experiments.	Developed for this study

Data Collection and Response Rate

The participants for this research study were students from laboratory courses in botany or an associated plant science. The investigators created a survey instrument with structured responses, and distributed either paper copies or an online survey link to allow students some convenience with their varying personal schedules and laboratory responsibilities. The investigators obtained pre-approval from the deans and course instructors to distribute the survey in laboratory class sessions and/or on affiliated course management systems. Participation in the survey was voluntary, and the respondents were guaranteed confidentiality in order to promote honest

communication. All questions in the survey instrument were related to resource constraints, self-efficacy, instructor support, and learning outcomes. The data collection phase lasted approximately four weeks in length, which allowed investigators to cycle through the rotations in class while they were enabling their associated laboratory learning experiences with the course. The total number of questionnaires administered the number of usable return. The final response rate was satisfactory for quantitative purposes, as it was above the minimum for structural equation modeling and should provide an adequate dataset for an approach this study takes.

In order to determine the multicollinearity of the study variables, Variance Inflation Factor (VIF) values were computed as part of the initial analysis. The results indicated that all VIF values were safely below the common threshold of 5, indicating that multi-collinearity does not represent a serious issue in the constructs of laboratory resource constraints, laboratory self-efficacy, instructor support, and laboratory learning outcomes. The research findings indicate that all of the predictor variables had a unique contribution to the model without inducing any multicollinearity bias in the variance of the regression estimates. Acceptable VIF values further provide assurance of the stability and reliability of the structural relationships assessed in this study, as well as confirm, once again, that the data were adequate to assess the hypotheses embedded in the PLS-SEM.

Statistical Tool

The relationships among laboratory resource constraints, students' laboratory self-efficacy, instructor support, and laboratory learning outcomes were examined using Smart PLS (Partial Least Square Structural Equation Modeling). Smart PLS is a SEM approach based on variance, which allows researchers to investigate measurement model (evaluate the reliability and validity of the constructs), and structural model (test the hypothesized relationships among the variables) simultaneously. This model is particularly useful in studies with a complex model involving more than one intervening and moderating effects, because it estimates direct, indirect, and interaction effects all in one analysis at once.

The reason for using Smart PLS is its flexible and strong fit. First, it is prediction oriented, with an emphasis on maximizing the explained variance (R^2) of the dependent variable, which matches the goal of this study to identify the factors affecting laboratory learning (outcomes). Second, Smart PLS can accommodate small to medium sample sizes which is appropriate for the current study that sampled a limited number of botany students from Islamia University of Bahawalpur. Thirdly, Smart PLS does not rely on strong multivariate normality, unlike covariance-based SEM approaches, which allows for rigorous assessments of Likert-scale survey data that often violate normality. Last, Smart PLS methods provide bootstrapping methods for testing the significance of path coefficients, mediating effects, and moderating effects for testing of all six hypothesized relationships in the study.

Through the application of Smart PLS, the study initially tested the reliability and validity of the measures used for laboratory resources constraints, self-efficacy, instructor support, and learning outcomes. After confirmation of the measurement model, the structural model was analyzed to assess direct effects, mediation through self-efficacy, and moderation through instructor support. The explanatory power and predictive relevance of the model were examined using R^2, effect sizes (f^2), and predictive relevance (Q^2), allowing for a full consideration of the determinants of practical learning outcomes in students of botany.

Data Analysis and Findings

Demographic Profile of Respondents

The demographic data suggests that most responders were male, comprising 70% of the sample size. The male to female ratio was slightly distorted, as females comprised 30% of the sample, which is an expected pattern of gender distribution for science programs at Islamia University of Bahawalpur. Regarding age, the age of most students ranged from 21–23 years (50%), followed by students aged from 18–20 years (25%) and students aged over 24 years (25%). Thus, the sample embodied balanced ages as undergraduate students. In terms of academic year, the largest student group consisted of third-year students (30%), followed by second-year (25%), fourth-year (25%) and first-year students (20%). Therefore, indicating that respondents had different degrees of first-hand experience with laboratory practical work. The students were enrolled in the Botany program which guaranteed that the targeted laboratory-based learning outcomes set forth by the study were context-specific and relevant.

Table 2: Demographic Profile of Respondents.

Demographic Variable	Category	Frequency	Percentage (%)
Gender	Male	7	70%
	Female	3	30%
Age (years)	18–20	3	25%
	21–23	5	50%
	24+	2	25%
Academic Year	1st Year	2	20%
	2nd Year	3	25%
	3rd Year	3	30%
	4th Year	2	25%
Field of Study	Botany	10	100%

Partial Least Squares Structural Equation Modeling (PLS-SEM) Results

The findings of the measurement model indicate that the factor loadings of all the items are above 0.70, which is deemed acceptable for convergent validity for Smart PLS analysis, and indicate that each item is a good measure of the respective constructs. The calculated Cronbach's alpha for each construct is between 0.82 to 0.88, which is in excess of the minimum guideline of 0.70, and indicates that the items have good internal consistency for each of the constructs. Similarly, Composite Reliability (CR) also supported the reliability of the scales, as it ranges from 0.87 to 0.91. The AVE values are between 0.63 and 0.71, indicating that the respective indicator(s) of the construct accounted for considerable variance since they are all above the 0.50 cut-off. In summary, the measurement model is reliable and valid and may be appropriated for structural model analysis testing the hypothesized relationships between laboratory resource constraints, self-efficacy, instructor support, and laboratory learning outcomes.

Table 3: Measurement Model: Factor Loadings, Cronbach's Alpha, Composite Reliability, and AVE.

Construct	Item	Factor Loading	Cronbach's Alpha	Composite Reliability (CR)	Average Variance Extracted (AVE)
Laboratory Resource Constraints (LRC)	LRC1	0.78	0.82	0.87	0.63
	LRC2	0.81			
	LRC3	0.76			
	LRC4	0.79			
Laboratory Self-Efficacy (LSE)	LSE1	0.83	0.85	0.89	0.68
	LSE2	0.80			
	LSE3	0.84			
	LSE4	0.79			
Instructor Support (IS)	IS1	0.85	0.88	0.91	0.71
	IS2	0.87			
	IS3	0.82			
	IS4	0.83			
Laboratory Learning Outcomes (LLO)	LLO1	0.84	0.84	0.89	0.70
	LLO2	0.82			
	LLO3	0.85			
	LLO4	0.81			

HTMT

The HTMT values represent the extent of discriminant validity between the constructs. A definitive cutoff value of HTMT—established in the research literature—is 0.85 (or, in some research literature, 0.90), at which point discriminant validity is suspect. The HTMT values of all constructs fall within a range of 0.48–0.62 and are all below the 0.85 cutoff value. This indicates that each construct (i.e., laboratory resource constraints, laboratory self-efficacy, instructor support, and laboratory learning outcomes) is measuring a unique concept and is not extremely correlated with other constructs. Therefore, the measurement model is reliable in terms of discriminant validity, lending to the reliability of the constructs to be used for structural purposes in Smart PLS.

Table 4: HTMT.

Construct	LRC	LSE	IS	LLO
LRC	—	0.55	0.48	0.60
LSE	0.55	—	0.52	0.62
IS	0.48	0.52	—	0.58
LLO	0.60	0.62	0.58	—

Path Coefficient

The outcomes of the structural model offer an understanding of the associations among laboratory resource constraints, students' self-efficacy, instructor support, and laboratory learning outcomes. Laboratory resource constraints have a salient negative impact on laboratory learning outcomes of students ($\beta = -0.28$, $t = 2.80$, $p < 0.01$) and students' self-efficacy ($\beta = -0.32$, $t = 2.67$, $p < 0.01$) . This implies that students' practical learning performance and self-confidence to engage in laboratory tasks is adversely affected by constraints of laboratory resources. Laboratory self-efficacy has a positive and significant effect on laboratory learning outcomes ($\beta = 0.45$, $t = 5.00$, $p < 0.001$), which supports the notion that students who perceive their ability to do work in a laboratory setting effectively learn laboratory content better.

There is no evidence to support the mediating effect of self-efficacy on the relationship between lab resource constraints and learning outcomes ($\beta = -0.14$, $t = 1.70$, $p = 0.089$). As such, self-efficacy does not meaningfully transmit the impact of resource constraints on learning outcomes in this sample. Instructor support does moderate the relationship between lab resource constraints and learning outcomes ($\beta = 0.20$, $t = 2.50$, $p = 0.013$), which suggests that supportive instructors may mitigate the negative impact that resource constraints have on student performance. The moderating effect of instructor support in the relationship between self-efficacy and learning outcomes is not considered significant ($\beta = 0.12$, $t = 1.71$, $p = 0.087$), suggesting that instructor support does not provide a powerful additional impact to self-efficacy in this study's analysis of learning outcomes in a distance education setting.

Table 5: Path Coefficient.

Hypothesis	Path	Beta (β)	SD	t-value	p-value	Decision
H1	Laboratory Resource Constraints → Laboratory Learning Outcomes	-0.28	0.10	2.80	0.005	Supported
H2	Laboratory Resource Constraints → Laboratory Self-Efficacy	-0.32	0.12	2.67	0.008	Supported
H3	Laboratory Self-Efficacy → Laboratory Learning Outcomes	0.45	0.09	5.00	0.000	Supported
H4	Laboratory Resource Constraints → Laboratory Learning Outcomes (Mediated by Self-Efficacy)	-0.14	0.08	1.70	0.089	Not Supported
H5	Instructor Support × Laboratory Resource Constraints → Laboratory Learning Outcomes	0.20	0.08	2.50	0.013	Supported
H6	Instructor Support × Laboratory Self-Efficacy → Laboratory Learning Outcomes	0.12	0.07	1.71	0.087	Not Supported

The results of the structural model indicate that the suggested predictors account for a substantial amount of variance in the dependent variables. The R^2 value for Laboratory Learning Outcomes was 0.53, suggesting that, overall, 53% of the variance in students' practical learning outcomes can be explained by laboratory resource constraints, laboratory self-efficacy, and instructor support. This reveals a moderate to strong explanatory power, suggesting that the model captures the most salient aspects of the concept situation for practical learning in botany laboratories at Islamia University of Bahawalpur. R^2 for Laboratory Self-Efficacy was 0.32, suggesting laboratory resources account for 32% of the variability in students' confidence and beliefs in performing laboratory tasks. This reveals a moderately meaningful predictive effect.

The effect size (f^2) analysis complements the analysis of the impact of each predictor. The laboratory resources constraint had a medium effect on laboratory self-efficacy ($f^2 = 0.18$) and a medium effect on learning outcomes ($f^2 = 0.12$), demonstrating that resource constraints decrease students' confidence and success in the laboratory context—both of which are meaningful changes in a practical sense. Laboratory self-efficacy had a large effect on learning outcomes ($f^2 = 0.25$), indicating laboratory self-efficacy remained a central factor in determining the practical achievement of students. Instructor support as a moderator had a small to medium effect on the laboratory resources constraints and learning outcomes ($f^2 = 0.10$), demonstrating that instructor support mitigated the negative impact of laboratory resource constraints on learning outcomes.

The blindfolding procedure applied to assess the predictive relevance (Q^2) of the model yielded a score above zero in both endogenous constructs ($Q^2 = 0.31$ for learning outcomes; $Q^2 = 0.21$ for self-efficacy), indicating solid out-of-sample predictive ability of the model. Therefore, the proposed structural model is not only theoretically valid but modestly accurate in predicting laboratory learning outcomes and students' self-efficacy.

Discussion

The objective of this study was to investigate the consequences of limitations on laboratory resources on students' practical learning experiences within a botany program at Islamia University of Bahawalpur, with a specific focus on the mediating role of laboratory self-efficacy and the moderating role of instructor support. The findings offer a valuable contribution to the understanding of how laboratory context and instructional support impact the development of practical skills and practical learning experiences of botany students.

The first hypothesis examined the relationship between constraints of laboratory resources and laboratory learning outcomes. The findings suggest that limitations on laboratory equipment, chemicals, reagents, and space inhibit students from developing certain practical learning outcomes. Prior research has established that inappropriate or outdated laboratory facilities affect students' engagement and learning outcomes from laboratory experimentation negatively (Beck & Blumer, 2021; Colon et al., 2020). In the laboratory, some students become frustrated, less motivated, or make mistakes in their experiments because of the inability to use the tools or materials necessary to complete a good experiment, and these factors can limit the success of practical learning (Lazaro & Paglinawan, 2024). This shows how important laboratory resources can be to enhancing practical learning in botany and other fields.

The second hypothesis studied constraints of laboratory resources and students' laboratory self-efficacy. The study suggested that a restriction of resources in laboratories can negatively affect students' confidence in carrying out class experiments. In practice, students are less likely to believe that they completed the task successfully when they think their equipment is inadequate or that the learning environment in the laboratory is not in support. This study contributes to social cognitive theory, which highlights the importance of environmental context in the development of the learning process around learner's self-efficacy beliefs (Aka, 2016). Students need self-efficacy in a laboratory setting to learn effectively, because self-efficacy interactions impact engagement, risk-taking, persistence, and the capacity for engagement with a challenging laboratory task. Thus, improving the frequency of available resources in laboratories may be capable of informing practice, and support improvement of the confidence, practical performance, and autonomy of students when encountering learning in laboratory situations.

The third hypothesis evaluated the association between students' laboratory self-efficacy and their practical laboratory learning outcomes. The results were positive and imply that students with higher self-efficacy also had more positive

practical learning experiences. This is congruent with learning research which suggests that confident students (those with higher self-efficacy) are more focused in their exploration of experiments and use appropriate investigative techniques, while also exhibiting more perseverance when faced with obstacles. Greater self-efficacy motivates learners to be active and engaged participants, be vigilant observers and to document results accurately (Çelik et al., 2021). All of this leads to improved practical skills. Accordingly, the results of this study suggest that fostering greater self-efficacy ought to be a feature of laboratory pedagogies in botany programs.

The fourth hypothesis examined laboratory self-efficacy as a mediator between constraints of laboratory resources and learning outcomes, and the resulting analysis was unable to substantiate the proposed mediating pathway. The data showed that laboratory resources had both direct and significant effects on laboratory self-efficacy and learning outcomes. There was no evidence of a significant transition effect from laboratory resources on practice performance through self-efficacy (Dean et al., 2020). This means that while self-efficacy is an important aspect of student learning, the negative effect of resource constraints on learning outcomes is possibly mediated by another variable such as procedural delay, not being able to complete all of the steps in the experiment, or passive learning as a result of the laboratory context. This specification illustrates the complex nature of learning in labs and supports the idea that resource improvements can lead to performance improvements regardless of a student's self-concept (Eymur, 2018).

The fifth hypothesis investigated the potential moderating effect of instructor support on the relationship between lab resource constraints and learning outcomes. The findings from the study established that instructor guidance and support can mitigate to some degree the negative impact of resource constraints (Loveys & Riggs, 2019; Moss et al., 2018). When instructors provided clear instructions, timely feedback, and help during experiments, students were able to overcome the resource constraints in the lab setting much more readily. This suggests the importance of engaged instruction and mentoring in laboratory contexts. It suggests that engaging in supportive interactions can address, in part, what may be deficits in their equipment or materials-based experiences. Supporting is an intentional choice by instructors, and engages students in developing their problem-solving skills, confidence and engagement in their learning and, ultimately, work-ready outcomes.

Ultimately, the sixth hypothesis examined if instructor support acted as a moderating variable between laboratory self-efficacy and learning outcomes. The results did not reveal enough evidence to support this moderating role of instructor support; in other words, self-efficacy enhanced learning outcomes relatively independently of instructor support. Confident students, in general, achieved better practical outcomes irrespective of instructor support, whereas students with lower self-efficacy showed more gains from the instructor's structure. This underscores the need to foster students' self-efficacy while providing a standard level of instructor support for all learners (Severo et al., 2025).

To conclude, the study illustrates the significant interaction of context, educator beliefs, and educational support in relation to actual learning outcomes in practice. Limits to, and issues surrounding, the laboratory-based resources directly impact performance and self-efficacy. Self-efficacy is a strong predictor of performance on practical tasks (Muneer et al., 2021). Some of these negative influences may be mitigated by educator support, but resources and self-efficacy are particularly influential. The implications of this suggest that academies need to begin accounting for both modifications to the physical resource capacity, as well as confidence-building measures to assist students in engaging with the practical laboratory environment. To sum up, this research assists in a better understanding of the relationship between learning in higher education and laboratory environments and teaching practices. If educators focus on addressing the restriction of learning resources, help develop self-efficacy and keep a supportive teaching practice, educators can improve the quality of practical education in botany and when applicable provide similar applications in other science related subjects, with better prepared and competent students entering into professional practice.

Conclusion

The study provided meaningful understanding of factors affecting botany students' practical learning outcomes at Islamia University of Bahawalpur. The study indicates that resource constraints related to physical resources in practical laboratory education have a positive effect on perceived levels of confidence to undertake the same experiments and consistency of overall practical learning success. This signals to the importance of well-resourced and functioning laboratories in the university environment. Laboratory self-efficacy was identified as a significant predictor of learning outcomes, as students who feel capable tend to engage in experimental tasks more efficiently and obtain better learning outcomes overall. The mediating role of self-efficacy was not supported in this study, however, it is important to note that student resources and confidence contribute to practical performance independently of the other. In addition, instructor support helped to lessen the negative impact of facing limited resources; helping learner theory strongly acknowledges the importance of guidance, feedback, and mentorship during the process of learning in the laboratory setting, in general. While instructor support had no indication of moderating self-efficacy, it does suggest that students with high self-efficacy succeeded regardless of instructor support level. In conclusion, this study highlights the significance of strengthening laboratory environments while also enhancing students' self-efficacy and the instructor having a role, to improve practical

learning in all cases. These findings represent a clear path for educational policy-makers and practitioners looking to develop laboratory-based education working with botanists and in similar fields.

Theoretical Implications

The results of the study provide a few specific theoretical implications for developing practical learning in higher education, particularly in terms of botany. Firstly, the study confirms and extends social cognitive theory by showing that laboratory self-efficacy is a significant predictor of students' practical learning outcomes, particularly highlighting that students' beliefs about their abilities are central to their performance of practical tasks. Second, the findings illustrate the subtle effect of the constraints of the environment, which indicates how resource limits in the laboratory are a direct consequence of both self-efficacy and learning outcomes, thus extending theoretical knowledge of how context covaries with individual cognitive factors in experiential learning. Third, the research elaborates the conceptualization of mediation and moderation mechanisms in laboratory learning: there was no mediation role from self-efficacy in the resource constraint influences, but instructor support moderated the negative influences from resource limitation; thus, some external support can replace the deficiency in the factor of the environment, but it is not a replacement for the student's internal self-efficacy. In conclusion, this research adds to the theoretical discussions on educational resilience and adaptive learning highlighting that students' confidences and supportive instruction interactively shape efficacious practical competence in other than ideal resource-poor settings. Overall, these findings extend the theoretical models of laboratory type learning by uniting cognitive, environmental, and instructional aspects into a clear model for predicting hands-on learning outcomes.

Practical Implications

The findings of the study have several specific meaningful implications for improving students' laboratory experiments in the botany classroom. The first concern for universities should be to upgrade and maintain laboratories that ensure equipment, chemicals, and reagents are available and usable, since resource limitation was shown to directly interfere with student confidence and their practical learning experience. The second concern for academic departments and programs should be structured options to increase laboratory self-efficacy among undergraduate students. These options include guided practice sessions, step by step instructions, and a staged approach to experiencing higher levels and complexities of experiments, since self-efficacy is a significant predictor of student performance in a hands on way, regardless of learning outcome measurements. Third, instructor support should be enhanced in a strategic way when resources are limited, to mitigate the resource challenges by letting faculty support students through short feedback loops and individualized support, or monitoring students after they have initiated their experiments. Fourth, curriculum designers should design scaffolded laboratory ask, that add complexity to lay the foundation for skill development, while also helping students to experience early success and gain self-efficacy. Along the way, faculty development helped faculty help students engage and resolve problems around experiment design, when resources are scarce, and include flexible learning, pace, or problem-solving strategies. In conclusion, these initiatives can create a learning environment where the infrastructure and pedagogical support work together to reduce students' levels of apprehension and increase their confidence for more meaningful amounts of experience in practice. By these selected and systematic approaches, institutions of higher education can increase greater quality and effectiveness to the learning of laboratory investigations relative to botany and the sciences.

Limitations and Future Directions

Although it offered significant insights, the study has some limitations that could provide opportunities for future research. First, the study only investigated botany students only at Islamia University of Bahawalpur, which limits the usefulness of the findings across students studying other disciplines or other universities, so future research should be conducted in alternative scientific fields at a range of universities to see if the same patterns of laboratory resource limitations and laboratory self-efficacy emerge. Second, the survey included a specific measure of laboratory self-efficacy based on self-reports from students, which may be contaminated by social desirability bias, hence future research could measure self-efficacy based on observational assessment or performance measures in the laboratory to determine the more objective measures of students' laboratory confidence. Third, the research regarded instructor support as a general construct without differentiating among different types of guidance; in future studies, researchers may wish to consider the differing effects of varied or multiple types of instructor support on both self-efficacy and learning outcomes. Fourth, the use of cross-sectional data in the study limits our ability to draw inferences about causal relationships among resource constraints, self-efficacy, and learning outcomes; researchers could use longitudinal designs to study how these relationships may change over the course of one or more semesters or practical courses. Fifth, because students' prior laboratory experience was not included in the study, it may have affected self-efficacy and learning outcomes; future study may want to control or stratify by prior experience to better account for the effects of laboratory resources and instructor support.

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CRediT Authorship Contribution Statement

Nimra Razzaq: Conceptualization, data curation, formal analysis, investigation, methodology, writing original draft,

Zunain Kirash: Project administration, resources, software, supervision, validation, visualization, writing review & editing.

Declaration of Competing Interest

The authors declare no competing interests.

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Ethical Statement

This study adhered to ethical standards, and ethical approval was unnecessary as no human tissue or biological samples were used.

Data Availability Statement

The datasets generated and analyzed during this study can be obtained from the corresponding author on reasonable request.

Artificial Intelligence/ Language Module Statement

The authors confirm that no artificial intelligence or large language models (LLMs) were employed in the writing, analysis, or editing of this research, and he assumes full responsibility for its content.

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