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Laboratory Work and Its Impact in Learning Chemistry at Middle Secondary Schools of Trongsa, Bhutan

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: The study aimed to assess the impact of laboratory work in learning chemistry among Middle Secondary School students in Trongsa. It explored the effect of laboratory work.
Study Design: The study employed mixed method research design that encompasses both quantitative and qualitative aspects of the research approach.
Place and Duration of Study: The study was conducted in the schools of Trongsa, Bhutan over a period of one year.
Methodology: Using a concurrent mixed-method approach, data were collected from 104 Class X students, 4 science teachers, 2 principals, and 2 chemistry laboratory assistants. Instruments included surveys, interviews, observations, document analysis, and checklists.
Results: Questionnaires were reliable (α=0.82 for teachers, α=0.71 for students). Additionally, a pre-post quasi-experimental design involving 102 students in experimental (N=50) and control (N=52) groups revealed significant impact. Experimental group achievement (M=16.98, SD=2.66) exceeded control (M=13.07, SD=3.30) with p=.000, t(100)=5.764, and Cohen's d=1.4.

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Conclusion: Laboratory work significantly enhanced Chemistry learning outcomes, as evidenced by the experimental groups' markedly improved post-test scores. The study recommended addressing constraints like teacher workload and competency to promote more effective use of laboratory work in Chemistry education.

Keywords: Laboratory approach; laboratory work; effect; science laboratory.

1. INTRODUCTION

The evolution of Bhutan's education system, transitioning from a traditional monastic approach to a modern, globally-connected paradigm, has been accompanied by notable reforms and commitments [1]. The Ministry of Education in Bhutan has displayed a dedicated effort to enhance the quality of chemistry education, adopting student-centered pedagogical methodologies with a strong emphasis on laboratory work [2]. This educational vision finds resonance in the Bhutan Vision 2020 Education Blueprint [3], which underscores the significance of science laboratory work across all grade levels. Consequently, science laboratories have emerged as fundamental components of enriched teaching and learning experiences, an observation emphasized by Hofstein [4].

Laboratory work, [5] is characterized by its hands-on and experimental nature, providing a platform to excel beyond theoretical concepts. Within Bhutan's educational framework, chemistry occupies a foundational role, interconnected with other scientific disciplines [6]. However, a worrisome trend is observed, with numerous chemistry students resorting to rote memorization rather than cultivating a profound comprehension of underlying principles, a challenge to effective chemistry education identified by Hofstein [4].

At the core of the laboratory experience lies the cultivation of conceptual understanding. Berger [7] highlights that laboratories enable students to bridge their observations with theoretical frameworks, thereby fostering a deeper grasp of concepts. This experiential understanding equips students to apply acquired skills in novel contexts. Despite the establishment of general science laboratories in Lower Secondary Schools and specialized laboratories for distinct subjects (Chemistry, Physics, and Biology) in Middle and Higher Secondary Schools, the limited presence of dedicated chemistry laboratories in only 52 out of 80 Middle Secondary Schools [3] raises concerns about equitable access and the quality of laboratory work.

As Bhutan's government continues to strive for enhanced educational quality, particularly in the realm of science education, the significance of chemistry education becomes increasingly prominent. Acknowledging science's pivotal role in socio-economic advancement, chemistry, acting as a central science connecting fields such as Medicine, Biology, Physics, and Geology [8], occupies a position of paramount importance. Nonetheless, the issue of low student motivation and interest in chemistry [9] has prompted government interventions in the form of curriculum reforms and teacher development programs. Within this context, the Ministry of Education underscores the pivotal role of laboratory work in enhancing the efficacy of science and chemistry education, emphasizing the indispensability of meaningful engagement with laboratory activities [10].

Geleta [11] emphasized that teaching chemistry without incorporating laboratory work weakens its effectiveness as a science. Research done by Colony [12] has shown that laboratory-based learning positively impacts student performance. The persistent issue of poor chemistry results among candidates in national examinations in Kenya, as highlighted by Thiong [13], serves as an indicator of not using laboratory during teaching and learning in secondary schools. A study by Daba et al. [14] further revealed that the absence of laboratory activities in science instruction contributed to declining student interest in chemistry and hindered academic performance.

Effective implementation of chemistry pedagogy necessitates the ability to seamlessly connect theoretical concepts to laboratory work [15]. Further, Vilaythong [13] highlighted the efficacy of laboratory activities in fostering understanding and knowledge construction through hands-on engagement. This notion was supported by Olubu's study [16], affirming the significance of chemistry laboratory learning in enhancing students' grasp of chemical concepts.

In Bhutan's context, where research addressing the role of chemistry laboratories in education is lacking, this study aims to bridge this gap by focusing on Middle Secondary Schools in the Trongsa Dzongkhag region.

1.1 Scope of the Study

The research investigation delved impact of chemistry laboratories in Middle Secondary Schools within Trongsa Dzongkhag. Data collection occurred between the 1st of August 2018 and the 31st of August 2018. The study focused on a specific demographic, comprising chemistry educators, laboratory assistants, and Class X students within the Middle Secondary Schools of Trongsa. The research was carried out across all Middle Secondary Schools situated in Trongsa Dzongkhag.

1.2 The Significance of the Study

The study might be of immediate benefit to Bhutanese Middle Secondary School students as they will be prepared to apply the conceptual understanding in real-life situations. The study may also bring out suggestions and ways of inspiring students in learning chemistry. The data and information obtained in this study may hopefully provide curriculum developers and policy makers with relevant information so to improve the use of laboratory in Bhutanese Middle Secondary Schools.

Additionally, it is expected that the findings of this study will possibly help the Ministry of Education, Royal Education Council and the two teacher education colleges in planning and budgeting to provide enough resources for a chemistry laboratory to support chemistry learning in schools. Moreover, the findings will hopefully influence further research.

1.3 Objective of the Study

This study aimed to explore the impact of laboratory work on learning chemistry. Specifically, it focused on evaluating and assessing the current status of the chemistry laboratory's effectiveness in enhancing chemistry learning for Middle Secondary School students of Trongsa Dzongkhag.

1.4 Research Question

What is the effect of laboratory work in learning chemistry?

2. METHODOLOGY

2.1 Research Design

The study employed a mixed method research design to collect both quantitative and qualitative data. This mode of methodology was selected primarily to enhance the researcher to gain an in-depth understanding of the laboratory approach.

2.2 Research Approach

Further, this study was focused on the concurrent mixed method design research approach. In this method, both quantitative and qualitative data would be collected, analysed, and interpreted (approximately) at the same time [17]. The researcher deployed this method due to time constraint, as this method requires shorter data collection time when compared to the sequential method.

2.2.1 Quantitative

This study used a quasi-experimental approach of the pre-test and [18,19] claimed pre-test, post-test design is the most appropriate design for measuring the impact or effectiveness of a program, where one group is treated and the other is not.

The quasi-experimental approach of the pre-test post-test design was suitable for this study because the performance of students taught using laboratory work (experimental group) was compared to the control group. In both the groups, a pre-test, and a post-test was carried out to determine the performance of the groups before and after the treatment.

This study also deployed a survey questionnaire consisting of close-ended questions. Through the questionnaire, the following data were collected: teachers and students' demography; effect of laboratory.

2.2.2 Qualitative

This study also deployed a qualitative research design to investigate the status and the ground reality of the chemistry laboratories.

The study used varieties of data sources to examine the impact and the attitudes of students and teachers on laboratory work. Further, teaching approaches used during the content delivery were also observed. The semi-structured interviews were conducted to principals,

chemistry teachers, laboratory assistants, and students. The participants were briefed on the purpose of the interview, and a general agreement was drawn to record and use the audio of the interview. Similarly, class observation, checklist, and document analysis were used in the study to gather more information.

2.3 The Sample of the Study

A sample is a small proportion of a population selected for the observation and analysis [15]. The sample in this study included class X chemistry students from two schools, two principals, chemistry teachers, and the laboratory assistants.

For the qualitative study, principals, laboratory assistants and chemistry teachers from two MSS were selected for the semi-structured interview. Similarly, 12 class X chemistry students from each of the MSS were selected for the semi-structured interview. Likewise, all class X students from two schools participated in the experimental and the control groups and for the survey questionnaires.

The sample of the study is summarized in the Table 1.

2.4 Study Area

The research took place in two Middle Secondary Schools located in Trongsa Dzongkhag. This area was chosen due to the students' relatively weaker performance in chemistry compared to other science subjects, and the researcher's familiarity with the schools' geography. Consequently, the researcher aimed to assess the influence of laboratory work on the students' academic performance.

2.5 Data Collection

The research was carried out over a span of four weeks during regular class sessions at Middle Secondary Schools (referred to as MSS). These sessions occurred three times a week, with each session lasting 55 minutes. Additionally, the chemistry teacher conducted extra classes within this period. To assess the students, four classes from the tenth grade underwent a pre-test focusing on the subject of Thermochemical reactions.

Both the Experimental Group (EG) and the Control Group (CG) took the pre-test in order to evaluate whether there were any significant differences between them. After subjecting the pre-test scores to an independent sample test, no statistically significant difference was found between the EG and CG. As a result, the group with the lowest average score was designated as the EG, while the group with the highest mean score was labeled as the CG.

During the intervention phase, the EG received instruction that incorporated laboratory work, delivered by the chemistry teacher from the sample school. On the other hand, the CG was taught using traditional methods. Following the intervention, both groups underwent a Student Achievement Test (SAT).

To gather data, close-ended survey questionnaires were distributed among both teachers and students. A checklist was employed to verify the availability of necessary materials in the laboratory and to ensure sufficient human resources within the chemistry department. In parallel, qualitative data was acquired through semi-structured interviews involving principals, teachers, and laboratory assistants. Furthermore, classroom observations and document analyses were conducted simultaneously.

To gauge the impact of laboratory work on learning chemistry, a post-test was administered. Lastly, 12 students from the EG, representing two MSS, were selected for semi-structured focused group interviews.

2.6 Data Analysis

Examining schools and classrooms through a combination of quantitative and qualitative methods is a growing direction for research in science education. The use of two or more methods of data collection in the study of some aspect of human behavior is called triangulation [17]. This method of analysis assures the validity of research through the use of a variety of methods to collect data on the same topic, which involves different types of samples as well as methods of data collection. However, the purpose of triangulation is not necessarily to cross-validate data but to capture the different dimensions of the same phenomenon [20].

2.6.1 Quantitative data analysis

The data collected through the quantitative method was summarized in the form of descriptive and inferential statistics. The data

was coded and entered into Statistical Packages for Social Science. In particular, the researcher employed the following statistics to analyse quantitative data.

1. The independent sample t-test was carried out to find the statistically significant differences between and within the CG and EG
2. The arithmetic means and standard deviation were used to analyse the factors included in the survey questionnaire.
3. A Pearson's correlation was used to find a linear relationship between two variables.
4. The participants' ratings on the frequency of occurrence of items provided in the closed-ended survey were grouped into five distinct levels adapted from Joy and Ventayen [9] suggest that each grouping needs to maintain an interval width of .80. Here, the mean score on the frequency of occurrence of the items was interpreted in terms of the level of severity of the problems. Table 4 displays the level of severity classified according to the range of mean score that

2.6.2 Qualitative data analysis

Qualitative Data Analysis refers to the procedures that are used to analyse the data and provide some level of explanation, understanding, or interpretation. The data collected through qualitative methods were analysed thematically.

3. RESULTS AND DISCUSSION

The examination of data collected from Middle Secondary Schools of Trongsa Dzongkhag revealed that incorporating laboratory work improved students' academic performance.

Table 1 The Sample for the study

Sl. No.	Items listed below	The sample for the quantitative study	The sample for the qualitative study
1	Schools	2	2
2	Principals	0	2
3	Chemistry teachers	4	2
	Laboratory Assistants	2	2
4	Chemistry students (104)	102 (quasi-experiment) 104 (for questionnaire 48-male, 56-female)	12 students from focused group interview) (2 groups consisting of three students in each school)
	Total population (n)	112	12

Table 2 Interpretation of the Scale Values I

Scale	Range	Frequency of Occurrence
5	4.21-5.00	Strongly disagree
4	3.41-4.20	Disagree
3	2.61-3.40	Neutral
2	1.81-2.60	Agree
1	1.00-1.80	Strongly agree

Table 0. Interpretation of the Scale Values II

Scale	Range	Frequency of Occurrence	Level of Severity	
5	4.21-5.00	Strongly agree	Always	Highest
4	3.41-4.20	Agree	Very often	High
3	2.61-3.40	Neutral	Neutral	Moderate
2	1.81-2.60	Disagree	Often	low
1	1.00-1.80	strongly disagree	Never	lowest

Adapted from Joy and Ventayen (2017)

The quantitative study was evaluated using descriptive statistics based on mean scores and standard deviation (SD) using Statistical Package for Social Science software (SPSS 22.0). In addition, independent sample t-test was performed to measure the statistically significant difference between students' pre-test and post-test scores. Statistical significance has been assumed when the alpha value is less than or equal to 0.05. Descriptive and inferential statistics were used to interpret the raw data. The mean, standard deviation, percentage and Cohen's d of post-test scores of the students were calculated.

For the survey questionnaires, the researcher received 100% participation from the teachers and students. The questionnaire consisted of Likert responses: Strongly Agree; Agree; Neutral; Disagree; and, Strongly Disagree, Very low; Low; Neutral; High; Very High, Poor; Fair; Good; Very good and Excellent. These responses were assigned values ranging from 1 to 5 respectively. SPSS was used for processing and analyzing the data obtained from the close-ended survey questionnaire. The questionnaire items were placed under themes by using composite function features of SPSS and the statistical procedures used both descriptive and inferential statistics. Further, the qualitative data involved the following personnel: 2 principals, 2 chemistry teachers, and 2 laboratory assistants in semi-structured interviews. Likewise, 12 students from both the sampled schools were taken from the experimental group for the focused group semi-structured interview.

3.1 Demographic Information of the Respondents

Demographic data obtained through the close-ended survey questionnaire is presented in Table 4. A total of 104 class X students participated in the survey, out of which 46.2% and 53.8% were male and female respectively.

The Table 5 shows that 75% of the chemistry teachers in the sample schools were male and 25% were female indicating the low percentage of female chemistry teachers in the schools.

3.2 Effects of Laboratory Work on Students' Performance in Chemistry

The study deployed 50 and 52 students in experimental and control groups respectively in order to find out the impact of laboratory work on students' performance in chemistry. The students of both groups were made to sit through pre-test and post-test. The experimental groups were taught through practical work in the laboratory. While the control groups were taught using a conventional method in the classroom [21].

Prior to the treatment, both the groups were taught the same content through the same teaching approaches. Then, test comprising of 3 questions were administered in order to check the performance level of the groups. The scores for both the control and experimental group from the pre-test are given in Table 6.

Table 4 Student Demographic Information

		Frequency	Percentage
Gender	Male	48	46.2
	Female	56	53.8
Age	14 and below	0	0
	15-16	44	42.3
	17-18	40	38.5
	18-19	16	15.4
	above 20	4	3.8

Table 5. Teachers Demographic Information

		Frequency	Percentage
Gender	Male	1	25
	Female	3	75
Qualification	Bed	3	75
	PGDE	1	25
Experience	below 5 years	2	50
	between 5-9 years	2	50

Table 6. Independent Sample T-test Pre-test

Group	No.of the student(n)	Mean	Std.deviation	t	Df	Sig.(2-tailed)
Experiment	50	13.79	4.25	.03	100	.970
Control	52	13.89	4.10			

It was evident that both 'experimental' and the 'control' groups possessed the students of equal performing level in chemistry subject. Further, it was found that the mean scores of both the groups were 13.79 and 13.89, respectively. The differences in means of the two groups were just 0.03. The independent sample t-test indicated no statistically significant difference in the pre-test scores obtained between the control and the experimental group, $p<0.05$ $t\ (100)$ =0.04, p=0. 0.97.

The post-test was conducted to both CG and EG to compare the students' performance level and validate the null hypothesis, laboratory work has no impact on academic achievement in learning chemistry. Independent Sample T-test was run interpret the data as shown in Table 7.

The comparison of post-test scores between the control and experimental groups were done by comparing mean, standard deviation, significant value, and Cohen's *d* value as shown in Table 7. The mean and standard deviation of the post-test of the experimental group were (M=16.98, SD=2.66) and control group (M=13.07, SD=3.30) respectively. The small value of standard deviation and Cohen's *d* value (1.4) suggest that there was a significant effect on students' academic performance by integrating laboratory work in learning chemistry. Similarly, independent sample t-test revealed the significance value less than the alpha level ($p<0.05$; $t\ (100)$ =5.76, p=0.000*), which* indicated a statistically significant difference in post-test scores obtained by the control and the experimental groups. This confirmed the test scores on the post-test for the experimental group were significantly higher than the control group. Thus, the null hypothesis (H_0), "laboratory work has no impact on learning chemistry" was rejected and the alternative hypothesis (H_1), "laboratory work has an impact on learning of chemistry" was accepted [22].

Likewise, Mwangi [23], who carried out the study in Public Secondary Schools of Machakos and Nairobi in Kenya also reported that the student groups who were taught integrating laboratory performed better with the mean test score of 15.73 than the control group whose mean score was just 14.18.

The study proved that the integration of laboratory work in teaching and learning of chemistry has enhanced students' performance and motivation in learning the subject. Similar opinions were shared by teachers and student participants during the interview [24-26]. Most of the interviewees stated that laboratory work besides improving the academic achievement, also boosts the interest and motivation towards the subject. Similarly, principal 1 (P1) shared:

> I think the use of a laboratory is a very effective means of teaching and learning chemistry. What students learn in the classes through textbooks can be visualized and seen in reality when the activity is performed in the laboratory.

Further, principal 2 (P2) stated, 'Theoretical, textbook-based learning does not provide the learners to use their psychomotor skills. The students would be just imagining things. Therefore, I really see the need for integrating laboratory approaches in teaching and learning of chemistry, wherever possible.' Likewise, a majority of the teacher interviewees (75%) also expressed the positive impact of the laboratory work in the subject. For instance, teacher 2 (T2) expressed, 'My students were happy and curious about laboratory experiments. The students are seen excited as soon as they are taken to the laboratory. They were also found to perform better on tests and discussions. S7 also echoes the same feelings and excitement of a laboratory visit during the intervention phase:

> I am very happy as we were taken to the chemistry laboratory for the first time this year. When I was there in the lab, I felt that I am learning more and better as we got to do an experiment ourselves. Till now, we have been learning chemistry in the classroom, we felt bored and monotonous sometimes, but today I was alert and engaged.

The students also confessed that they were very positive about laboratory learning. Most of them

Table 7. Independent Sample T-test Post-test

Group	N	Mean	Std. Deviation	T	Df	Sig. (2 tailed)	Cohen's d
Posttest experimental	50	16.98	2.66	5.76	100	.000	1.18
Posttest control	52	13.07	3.30				

Cohen's d value: d=0.2-small effect, d=0.5-medium effect, d=0.8-large effect

Range	Level of Severity
• 4.21-5.00	Highest
• 3.41-4.20	High
• 2.61-3.40	Moderate
• 1.81-2.60	Low
• 1.00-1.80	Lowest

Table 8. Impacts of the Chemistry Laboratory

Statement	Mean	opinion
I perform better in test and exam when taught through laboratory integrated lesson.	3.61	high
The use of laboratory increases my motivation to take part in new learning.	3.91	high
The use of laboratory enables me to express my idea and thought better.	3.81	high
The use of laboratory in learning broadens my knowledge and understanding of my subject.	4.36	highest
The use of laboratory increases my confidence to participate actively in the class.	3.98	high
The use of laboratory encourages me to communicate more with my classmates.	4.14	high
The use of laboratory helps me to be more creative and imaginative.	4.15	high
Average mean	3.99	high

felt that learning chemistry through laboratory approach is interesting and motivating. S1 shared, 'I was excited to touch the apparatus and observe the chemical reactions. I was nervous at the beginning, but also felt motivated to carry out the experiment myself.' S6 shared a similar opinion:

> Previously, I had learned about sodium metal in class, but I hadn't seen it in real life until now. Being in the lab this year allowed me to witness its strong reaction with water. This hands-on experience has really boosted my interest in learning chemistry. I'm certain that this will help me do better on my upcoming chapter test.

The mean scores from the survey ratings have been also used to measure the impact of the laboratory in learning chemistry and the scores were interpreted using Joy and Ventayen's guide [13].

The survey ratings of students revealed that the chemistry laboratory has high impact on learning Chemistry with the overall mean rating of 3.99, as shown in Table 8.

4. CONCLUSION

In educational contexts worldwide, laboratories are widely recognized for their effectiveness in teaching chemistry. This study focused on Trongsa Dzongkhag and evaluated the impact of laboratory work on chemistry education. The research employed a mixed-methods approach, using various tools such as student achievement tests, surveys for students and teachers, interviews, and classroom observations.

The study included 104 students for surveys and 102 students in a quasi-experiment, along with chemistry teachers, laboratory assistants, and principals. Schools and participants were purposefully selected. Two groups were formed from different schools, and their chemistry teachers delivered instruction while being observed by the researcher.

After the instructional phase, both groups underwent pre-test and post-test assessments. The experimental group, taught with laboratory methods, outperformed the control group taught with conventional techniques, with a significant mean score difference of 3.16. The calculated

Cohen's d value of 1.4 further emphasized the positive effect of laboratories on academic performance.

Beyond statistical superiority, qualitative insights highlighted the substantial benefits of laboratory-based learning in enhancing chemistry education in Middle Secondary Schools.

In conclusion, this study underscores the valuable role of laboratory work in elevating academic achievements. It emphasizes the importance of integrating laboratory approaches into chemistry education to create enriched learning environments and foster improved academic accomplishments.

5. LIMITATION OF THE STUDY

This research was conducted with a restricted sample size, specifically focusing on class X students from the two Middle Secondary Schools within Trongsa Dzongkhag, along with the participation of four chemistry teachers. The timeframe allocated for the study was relatively brief, spanning just one month. Consequently, this abbreviated duration did not provide ample opportunity to comprehensively observe the complete teaching routines of the chemistry teachers throughout the entire day.

Furthermore, it is essential to acknowledge that the study encountered notable constraints primarily linked to the scarcity of accessible literature within the realm of laboratory studies in Bhutan. As a result, the research had to heavily lean on investigations conducted in other nations to compensate for this lack of local literature.

CONSENT

The informed consent forms effectively communicated the objectives and purposes of the study. Participants were informed that their involvement in the research was voluntary in nature. All individuals who participated acknowledged this by signing the provided consent forms.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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