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Factors Affecting Higher Secondary Students' Ability to Conduct Chemistry Experiments

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ABSTRACT

This study examines the factors influencing students' performance in chemistry laboratory skills and proposes strategies for improvement. Conducted at a government female college in Bangladesh, the mixed-method research involved 50 higher secondary students and 3 chemistry teachers through random sampling, and 6 students via purposive sampling. Data collection utilized questionnaires, interviews, and focus group discussions, analyzed through thematic analysis and descriptive statistics. Findings revealed challenges in performing heating and cooling processes and applying theoretical knowledge, attributed to the students' limited prior knowledge, negative attitudes toward practical work, teachers' instructional methods, feedback practices, and inadequate laboratory facilities. Strategies to address these issues include authentic performance assessments, teacher training, and increased funding for laboratory resources. The study provides actionable recommendations for administrators, educators, and policymakers to enhance chemistry education and offers insights into improving laboratory learning in the global context and, particularly within resource-constrained settings like Bangladesh.

1. Introduction

1.1. Background of the Study

Chemistry is the branch of physical sciences that discusses chemical composition, physical and chemical properties of matter, and relevant laws and principles (Ebbing, 1996). Theoretical chemistry provides a basis for how fundamental laws and principles governing the changes in the properties of matter are applied to explain phenomena. Practical work refers to activities that science students perform in the laboratory either independently or in small groups. It is also termed laboratory work (Köller et al., 2015).

The importance of laboratory work is a widely accepted phenomenon in chemistry education. Feisel and Rosa (2005), as cited in Radin-Salim et al. (2013), suggested that it established a connection with theoretical knowledge. Jakeways (1986) concluded that laboratory work

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played a vital role in science teaching-learning as it helped students understand scientific processes and concepts. Another study conducted by Woolnough (1994) found that laboratory work improved students' communication skills and promoted motivation in science learning. In contrast, Abrahams and Millar (2008) concluded that conventional practical work is an inappropriate method of science teaching-learning because it cannot represent scientific investigation. Recipe-style experiments were not useful for fostering students' creativity as they required no higher-order cognitive skills to use and were a waste of time (Hodson,1990).

Historically, it was the eighteenth and nineteenth centuries when science education, laboratory work, and direct experimentation were becoming important (Nakhleh et al., 2002). A standard reference book for laboratories was first written in the 1860s, where the author emphasized that education is meaningless if it relies only on memorizing Davis (1929), as cited in Nakhleh et al. (2002). Fay (1931), as cited in Blosser (1983), concluded that laboratory activities were first introduced into high school curriculum in the 1880s. The science curriculum was redesigned, and practical work was used to increase students' engagement in scientific investigations during 1960. Between 1960 and 1980, several educational research were carried out to find the salient features of an effective laboratory. Tobin (1990) concluded that practical work can be a meaningful phenomenon for students if they have opportunities to apply their science knowledge in the laboratory instead of only memorizing it. Hofstein (2004) performed a review study to find dissimilarities in learning between theory and laboratory classes. At that time, there were extensive reforms in the science curriculum and practical work in chemistry.

There have been several studies regarding different aspects of chemistry practical work. Anza et al. (2016) reported that teachers' poor knowledge, lack of laboratory facilities, and unsafe laboratory environment were the major reasons for students' low performance in practical work. Another study on secondary school students' performance in practical work found that the most significant causes were a lack of trained teachers, laboratory facilities, and language communication (Hassan et al., 2015).

In the context of Bangladesh, recipe-style chemistry experiments were the most common category of laboratory work carried out at a higher secondary level. The research conducted by Ashique et al. (2022) to assess the existing status of laboratory work and the influential factors of chemistry practical work at the secondary level. They found inadequately trained chemistry teachers and low laboratory facilities as the major influencing factors.

1.2. Problem Statement

Students' performance in chemistry laboratory work is often determined by how they can carry out experiments. Though relevant theories were explained, and instructions and laboratory facilities were provided, most students were unable to conduct experiments for unknown reasons. Since the final assessment method included the marks obtained in practical work, they were getting poor scores in chemistry. Furthermore, analysis of previous years' examination results suggested that only 15% of students got satisfactory grades (A^+ or A), approximately 75% performed poorly (C or below), and 10% failed in the chemistry practical. After higher secondary, few students at this college got admitted into higher studies for courses such as medicine, engineering, and technology due to poor laboratory skills. Therefore, the aim of this work is to explore the factors resulting in students' poor performance and to make appropriate recommendations.

1.3. Rationale

It was expected that students would be able to do chemistry experiments that were designed to apply theoretical concepts in laboratory settings. However, it was found that most students were unable to perform investigations for unknown reasons. This mediocre performance in experiments was affecting their overall grades. The problem remained unresolved for many years. The college administration and the department of chemistry tried to find out the reasons, though no systematic investigation was made.

Researchers investigated the implications of poor performance in laboratory work. One such study was done by Otieno (2012), who indicated that poor laboratory work performance hindered students' access to higher studies in science and technology. The study also found that poor performance affected their societal life and production in the industry. If students are not engaged in laboratory work for weeks, their interest decreases, affecting their performance (Regan & Childs, 2003). Furthermore, Akani (2015) investigated the implications of laboratory teaching on students' achievement and concluded that if students' engagement in laboratory work goes gradually down, students would have little or no knowledge of practical science. Consequently, graduates lack pre-requisite qualifications for courses such as medicine, engineering, agricultural science, and related careers.

However, there is a gap in the existing literature about factors affecting higher secondary students' performance. Therefore, it is important to identify the factors affecting students' laboratory performance so that appropriate measures can be taken to enhance students' hands-on experience and retention.

1.4. Research Objective

a) to identify the factors affecting students' ability to carry out chemistry practical work.
b) to improve students' performance in laboratory work by making relevant recommendations.

1.5. Research Questions

a) What are the problems faced by higher secondary students when conducting chemistry experiments?
b) Why are higher secondary students facing problems when conducting experiments?
c) What are the possible strategies that can be adopted to address these problems?

1.6. Significance of the Study

This work unveiled long-standing issues regarding students' performance in laboratory work, and it would help administrators, teachers, and students facilitate learning by doing. Educators and policymakers can also use the findings of the research to implement improved laboratory learning. In addition, it adds important aspects to chemistry laboratory education. Since the research aimed at identifying the factors hindering students' ability to perform practical work, its beneficiary would primarily be the students at this college and the country's chemistry education system eventually.

1.7. Theoretical Framework

The study grounded in the constructivist learning theory, a student-centered learning approach, primarily attributed to Piaget (1952) and later expanded by Vygotsky (1978) through the concept of social-constructivism. Constructivism theory emphasizes that students themselves construct new knowledge and understanding based on their prior knowledge and experiences

(Uddin et al., 2024). In the context of higher secondary student conducting chemistry experiments, the framework suggests that student hands-on experience help develop deeper understanding and enhance retention. To perform chemistry investigations, students apply chemical theories, manipulate materials, observe changes, and analyze the chemical data based on their earlier skills in practical work.

From a social-constructivist point of view knowledge is co-constructed (Vygotsky (1978), while working in small groups during laboratory work, students interact and collaborate with their peers to construct knowledge. If students work in group and share their ideas, it enhances their understanding and problem-solving skills, fostering a deeper grasp of experimental procedures (Hofstein & Lunetta, 2004; Uddin & McNeill, 2024).

Effective teachers' facilitation teaching-learning process and the availability of resources can impact learners' performance, especially in the context of Bangladesh (Uddin et al., 2024; Uddin & Bailey, 2024). Firstly, while following steps to complete the procedures of chemical investigations, students easily find their gaps in the learning, which may have originated either at their secondary-education level or in theory classes. Consequently, they seek support from teachers. Through teacher guidelines and directions, students refine their laboratory set-up and procedures, which aligns with Vygotsky's notion of scaffolding (Vygotsky, 1978). Secondly, the lack of appropriate instructional practices caused by teachers' attitude and inadequate professional development programs can hamper the process (Uddin et al., 2024; Uddin & Bailey, 2024). In other words, if teacher cannot establish connection between theoretical concepts and laboratory investigations or if the support from teacher become does not meet their needs, it can lead to student demotivation. Moreover, limited access to laboratory resources, often caused due to large class size and large groups, can further worsen student learning experiences, restricting their ability to perform effectively in the laboratory.

Overall, the framework puts emphasis on creating environment that promotes student active learning opportunities through collaboration and higher order thinking skills. The researcher in this study integrates constructivist and social-constructivist principles to explore the effect of student prior knowledge, teacher attitude, professional development programs, group investigations and laboratory resources on students' ability to perform chemistry investigations.

2. Literature Review

This section reviews relevant literature about various aspects of chemistry practical work such as students' prior knowledge, teachers' factors, laboratory factors and group investigations determining students' understanding of scientific concepts, engagement, attitude and performance in laboratory work.

2.1. Students' Prior Knowledge

Learners' pre-existing knowledge was an important factor to enhance in-depth understanding (Uddin & McNeill, 2024, Husain & Uddin, 2024). However, students at this college were of medium calibre based on the analysis of their secondary academic results. Their laboratory skills, which were supposed to be achieved at school, were not satisfactory. They could barely follow demonstrations and safety rules due to gaps in prior knowledge. Interview protocol and focus group inform the effect of students' pre-existing knowledge on their laboratory performance in section 4.

Students' prior knowledge was the most important area in which researchers tried to find out how it affected students' laboratory skills. One such study was done by Johnson (2016), who tried to find the impact of prior exposure to laboratory instruments on the achievement of process skills and academic performance in chemistry at a secondary school in Giwa Zone, Kaduna State, Nigeria. Researchers wanted to explore the relationship between the involvement of students in pre-laboratory activities and achievement in process skills. The findings indicated that students' academic performance was significantly high, and their process skills went up when they were exposed to laboratory apparatus before they took part in the laboratory.

Another similar research was done by Schmid and Yeung (2005), who attempted to explore how a pre-laboratory work module impacted students' academic performance in a first-year chemistry laboratory course at the University of Sydney. In this study, the investigators provided students with an online laboratory module that they could access before they performed certain experiments. Researchers instructed students about the importance of the pre-laboratory work. The findings indicated that students who were comparatively weaker in chemistry performed well as they had a deeper level of understanding and were aware of what and how they were required to do. It did not provide details of how the same can be applied in face-to-face methods. Hailikari et al. (2008) performed a survey to measure the impact of several types of prior knowledge on students' achievement for instructional design purposes. It found that students' prior knowledge had a significant impact on students' achievement. Though successfully identified different types of prior knowledge, it made a tangential discussion on how prior knowledge affected students' laboratory skills.

While these students-related factors build a strong foundation for chemistry laboratory performance, the role of teachers in providing laboratory instructions, demonstration techniques and authentic assessment can have influence how students perceive and engage with laboratory activities.

2.2. Teachers' Factors

In the context of this college, teachers' laboratory demonstrations and attitude affected students' laboratory performance. Students could not follow teachers' demonstration as they were less accessible to the students, and demonstrations were performed long before. In addition, lack of professional development activities such as training, workshop and seminar demotivated them.

Teachers' factors were another aspect which was also studied by several researchers. Ashique et al. (2022) attempted a work to find out the status of secondary practical work and to determine the factors affecting students' ability to perform chemistry laboratory performance. They found a couple of negative aspects such as teachers' expertise in practical work, limited laboratory facilities, insufficient time allocation.

One of the key factors that resulted in students' inferior performance in chemistry classes was teachers' lack of laboratory practice resulting from teachers' attitudes. (Kenni, 2019). In this study, the researcher investigated how teachers' factors affected secondary school students' participation in chemistry laboratory classes. The result of the work indicated a positive correlation between teachers' attitudes, experience, and skills and students' participation. It criticized teachers' laboratory work skills but did not provide full details. Ogunleye (2010) carried out research to implement chemistry laboratory work in senior secondary schools. In this study a questionnaire was administered to 250 teachers, who took part in the survey, to identify why students performed poorly in the chemistry laboratory. The result explored some key factors that were negatively associated with teachers' qualifications, teachers' roles, and teachers' seriousness about laboratory work.

In contrast, whereas most of the studies emphasized the different aspects of chemistry teachers, the literature on how training for professional development of chemistry teachers affected students' performance was quite limited. One research study was conducted by Cossa and Uamusse (2014), who tried to understand the influence of in-house training programs for biology and chemistry teachers on their perception of practical work. In this research, 17 secondary school teachers participated as respondents and were given training on laboratory work for 5 days. The result showed that before the workshop, teachers' views about the importance of laboratory work were low, whereas after this in-service program, their understanding of the significance of practical work improved.

Following this line of inquiry, the next key consideration is how group investigation, another factor, impacts student engagement, collaboration and performance in chemistry laboratory work.

2.3. Group Investigations

In the context of this college, students performed investigation in groups consisting of approximately 10-15 members each. It was observed that students found it comfortable working in groups because they could share their ideas and opinions while making scientific predictions. Since they were working in groups, it was easy for them to understand scientific concepts deeply and think critically. Nevertheless, the challenge faced by students regarding group investigation was the inaccessibility of individual participation in the work.

Wachanga and Mwangi (2004), in their survey, tried to understand the impact of collaborative learning on students' achievement in chemistry laboratory work. They reported that placing students in groups had a positive impact on their learning, and it was independent of the gender of students. In contrast, Shibley and Zimmaro (2002) conducted a study to explore the impact of group work in chemistry laboratories on students' attitudes and performance. They concluded that their survey did not find any significant difference in the performance of students for short-term achievement, though it had a positive impact on classroom performance, the course, and the collaborative learning experience.

However, one of the problems that was noticed during group investigation was that some members of the groups could not take part in hands-on activities either because they were anxious or they had little access to participate in experiments, especially when the group size was 10 or more. This observation was in line with the work of Sharifah and Lewin (1993), as cited in Abdullah et al. (2007), who investigated the impact of group investigations. They said that the larger group size hindered students' active participation and argued that 2 to 3 members of every group played inactive roles, which resulted in the acquisition of a lower level of scientific skills. Similarly, Abdullah et al. (2009) performed research to understand the effect of personalized laboratory approaches through microscale investigations. It found that the approach was beneficial for students to understand scientific concepts of chemistry; however, the study did not find any significant difference in attitude and motivation among students.

In addition to the above-mentioned factors, the next important one that can impact student engagement and performance in chemistry practical work includes laboratory environment.

2.4. Laboratory Factors

At this college, practical work was conducted in a medium-sized laboratory containing 75 students, where laboratory facilities were not accessible to everybody due to limited space.

Furthermore, students had no freedom to choose the topic of investigation in recipe-style experiments. Therefore, while few students were conscious of teachers' instructions, many of them were reluctant as they could not follow teachers' demonstrations.

Regarding the impact of laboratory facilities on students' performance, a study conducted by Olubu (2015) tried to unveil how laboratory environments impacted the academic achievements of secondary chemistry students. It reported five influencing factors such as students' cohesiveness, open-endedness, integration, rule clarity, and material environment. Students' cohesiveness refers to how well they work and support one another. Open-endedness refers to students' freedom to choose learning according to their interests. The integration characterizes the relationship between theory taught in classes and practical work. Of them, the laboratory materials environment was the most influential factor, whereas rule clarity, i.e., how laboratory rules are practiced in theory and laboratory classes, was the least.

Similar research was done by Rahmawati and Koul (2018) who conducted the study to find the opinions of Indonesian university students about their chemistry laboratory learning environment. They argued that students learn better if they can explore their interests and work in a better laboratory setting. Though the research emphasized only the physical environment of a chemistry laboratory, such as laboratory space and equipment, it overlooked the importance of students' freedom of choice observed in inquiry-based learning and teacher-student relationships.

Freedman (1997) carried out research to investigate how laboratory instructions, approaches, and attainment are related to one another. It found that students who received laboratory instruction regularly performed better in the examination and had a positive attitude toward science and achievement in science knowledge than those who did not. Another similar study conducted by Musengimana et al. (2021) concluded that laboratory instructions have positive effects on students and have significant impacts on students' attitudes toward science during hands-on and activity-based laboratories (Fraser, 1980).

In contrast, Monica et al. (2015) in their work criticized conventional teacher-centered cook-book experiments in which students just follow the procedure and have trivial things they can do independently. In this type of laboratory class, students are often placed in groups to do certain experiments and do not engage their minds. Another work was carried out by Crandall et al. (2015) to compare students' satisfaction levels between virtual and conventional wet laboratories. The findings of their work suggest that students had no significant preference over the two laboratory types. Advocates of simulated labs said that they preferred virtual settings because they could use the laboratory with more flexibility, whereas the supporters of wet labs argued that it was helpful as they could work in groups and had instant access to laboratory instructors.

From the above-mentioned review, it was evident that students' pre-existing knowledge, teachers' attitudes and motivation, group investigation and laboratory environments were interesting areas for most researchers. In addition, there were also researchers who investigated the effect of group investigations on student laboratory performance. However, the review did not find any successful work that fully could reveal factors affecting college students' chemistry laboratory performance, especially in the context of Bangladesh.

2.5. Research Gap

Laboratory work is considered to be the most important aspect of chemistry education to enhance student conceptual understanding and retention, though it has remained unexplored in the context of higher secondary level. A number of studies have highlighted the importance of laboratory-based chemistry education in fostering students' inquiry and higher order thinking skills (Hofstein & Lunetta, 2004). However, very few attempts, and almost no study in the context of Bangladesh, have been made to examine how the factors such as student prior knowledge, teacher attitude and professional development and laboratory resources affect students' chemistry practical work.

Existing literature often emphasized the general science education and lacked the context instead of focusing on specific challenges in practical chemistry. In Bangladesh, some researchers such as Ashique et al. (2022) attempted to address the issue but only at the secondary level. Similarly, studies done by Ronoh (2021) and Chepkorir (2023) focused on secondary school settings and came up with recommendations, e.g., computer-based laboratory simulation for enhancing student inquiry skills, might not be effective for higher secondary education settings.

The role of teacher in scaffolding is widely studied phenomenon, yet there remain scopes to reveal how teacher attitude, professional development programs and instructional practices collectively impact student performance. Furthermore, though some studies acknowledge the impacts of resource constraints, they remain incomplete because of considering it, alongside instructional practices and student preparedness, only for developed countries (Onwu & Randall, 2006).

Therefore, the study aims to explore the factors that negatively impacts students' performance in chemistry practical work, which are crucial for bridging the knowledge gap, ensuring students' deeper conceptual understanding and improving retention.

3. Research Methodology

This chapter presents a methodological procedure used in the study, including the type of methods, context of the research, sample selection procedure, and data collection. In addition, it discusses the validity and reliability of the research, research instruments (RI) used, data analyzing techniques, and finally, the piloting of the work.

3.1. Research Design

This research adopted a mixed method approach to identify the factors negatively influencing higher secondary students' laboratory performance. Its advantages include it allowed to add three most important components, including voice of respondents, in-depth analysis and increased validity according to Chaumba (2013). Since the study would deal with large samples through random and purposive sampling, only the questionnaire might not give a complete picture. Therefore, the interview protocol and focus group would also be employed as RI.

3.2. Research Context and Sampling

Students were taught relevant theories, laws, and principles in theory classes. Before participating in group investigations, students were given appropriate instructions, and then experiments were demonstrated by the teachers. There were around 5-10 members in each group. However, college administration and teachers noticed that when students were told to conduct experiments themselves, they were unable to perform.

The target population was 3 chemistry teachers and 300 female students at this female institution. It used simple random sampling and purposive sampling methods. Simple random sampling consisted of 50 female students and 3 chemistry teachers from the target population.

Since there was no specific information known about students who were performing poorly, simple random sampling would reflect the true scenario when administering questionnaires to the sample. Purposive sampling was also used, where 6 students represented the population. Both top- and low-grade students were selected as the sample so that the true background of the research could be reflected.

3.3. Method of Data Collection

The mode of data collection was face-to-face. Qualitative and quantitative data were gathered on different days. Before data gathering, permission was sought from the principal of the educational institution concerned. The researcher requested the head of the institution to identify a teacher as a contact person. Respondents were requested to provide their free, honest, and unbiased responses. They were also confirmed that their responses would be anonymized and treated confidentially during and after the study. Furthermore, they were told that the participation is entirely voluntary; however, their opinion would be highly appreciated.

On the date of administration of questionnaires, the appointed teacher brought the students to the designated classroom after regular classes. When students arrived at the classroom, they were given a thorough explanation of the purpose. Students who showed interest in participating in the research were given a hard copy of the questionnaire so that they could follow the instructions and ask any questions before completing it. Students were instructed to save the investigator's WhatsApp number on their mobile devices for contact. They were also told that it would take approximately 10-15 minutes to complete the questionnaire and that if anybody was involved in any sort of incident that may make the validity of the data questionable, they would immediately be removed from the completed batch.

Regarding FGD and the interview, FGD was carried out first and then the interview. Both chemistry teachers and students were given ideas about the type of questions they would be asked in advance. They were also notified that the total conversation and discussion would be recorded and stored, and they can access it if they wish. Once they signed the consent form, the interviewer started interviewing the interviewees separately to avoid prejudice.

3.4. Research Validity and Reliability

Selection of the target population and the sample were appropriate in terms of size and representation. Appropriate, detailed and clear instructions were given to respondents, and it was maintained by the investigator at all stages of the study.

In the quantitative method, the questionnaires developed by the investigator were checked and re-checked by chemistry teachers and experts. The number of statements in the questionnaires was 18, which was in line with the suggestions made by Nunnaly (1994), as cited in Drsot (2011). To avoid bias and to obtain true responses, respondents were notified well before filling in the questionnaires. Respondents' behaviors were monitored strictly when they responded. The data obtained were analyzed with great care so that it could be reproduced by other researchers.

In the qualitative method, when the interview and FGD were carried out, they were done separately and cautiously to avoid prejudice and any activities that might hinder obtaining the reliability of the research. The RI used for qualitative methods were designed in such a way that they could reflect the true scenario and measure the variables. The findings of the work were in agreement with other researchers.

3.5. Research Instruments

Questionnaires, interview protocol, and focus groups were used as RI_S developed by the investigator. 'Questionnaire for students' consists of two sections administered to students (See Appendix 1). Its 'Section A' asked students to give their personal information, and 'Section B' contained 20 close-ended questions asking students to rate their ability on a five-point Likert Scale. When the responses from the students were obtained, another similar sort of 'questionnaire for chemistry teachers' consisting of two sections administered to chemistry teachers (See Appendix 2) was employed to validate students' responses. Similarly, its 'Section A' asked teachers to give their professional details, and 'Section B' contained close-ended questions, where teachers were requested to rate their student's' performance on a five-point Likert Scale.

Regarding focus groups, students discussed the reasons why they found chemistry experiments difficult. The length of the group discussion was 20 minutes in total, which was also recorded on a mobile device.

During the interview, every teacher was asked about 3-4 open-ended questions and some relevant follow-up questions to obtain a clear picture. The length of the interview for every teacher was approximately ten minutes, which was recorded on a mobile device. The total amount of interview time for teachers was roughly 30 minutes.

3.6. Method of Data Analysis

Descriptive statistics was used to analyze quantitative data obtained from RQ_1 through questionnaires. The responses were rated on a five-point Likert Scale ranging from (1 = Very Weak), (2 = Weak), (3 = Average), (4 = Good) to (5 = Very Good). To find the most significant features easily, the frequencies of the Likert Scale raters 'Very Weak' and 'Weak' were combined to get the frequency and percentage of a new rater 'Weak.' Similarly, the frequency of the raters 'Very Good' and 'Good' were combined to obtain frequency and then a percentage of the rater 'Good.' However, the Likert Scale rater 'Average' was kept the same while calculating the frequency of distribution. Percentage, mean and standard deviation were calculated using a Microsoft spreadsheet to quantify the findings of the study.

Thematic analysis was employed to analyze the qualitative data obtained through interview and FGD. Audio recording of interviews and FGD was transcribed by the investigator himself to get a thorough overview of the data. While transcribing, some notes were taken to get preliminary ideas for codes. Answers to the RQ_2 and the RQ_3 obtained from FGD and interview were based on the findings of the RQ_1.

4. Findings

This chapter presents findings and discussion of the study, and interprets them from constructivist point of view. The findings and the relevant discussions were structured based on the research questions.

Two questionnaires (one for teachers and another for students) were used to find the answer to RQ_1 for the quantitative method. The result of RQ_1 was employed to get the answers to RQ_2 and RQ_3 for the qualitative method, in which the interview protocol and focus group were used as the RI_S. The RQ_3 was answered based on the findings of RQ_2 and RQ_3.

4.1. Findings of the First Research Question

First research question was generated to find the challenges faced by students during investigations. The table 1 shows the result of $RQ_{1.}$ It was clear that 5 out of 18 statements were challenging tasks for most students. The major difficulties were: (1) performing heating process (2) performing cooling process (3) applying theory (4) making appropriate predictions and (5) following safety rules.

Table 1.
Statistical data regarding challenges students experienced when doing chemistry experiments

SL No	Statement	M	SD	Percentage (%)	Rank
17	I can perform the heating process	1.91	0.94	75.5	1
18	I can perform cooling process	2.08	1.16	69.8	2
02	I can apply theory when doing practical work	2.53	1.29	64.2	3
07	I can make appropriate predictions	2.57	0.96	60.40	4
01	I can follow appropriate safety rules for an experiment	2.60	1.57	52.8	5
15	I can safely handle laboratory chemicals	2.66	0.77	49.1	6
3	I can follow the procedure of an experiment	2.94	1.25	39.6	7
6	I am able to make accurate interpretations	3.08	0.90	37.7	8
5	I can make accurate observations	3.10	0.87	30.2	9
4	I am comfortable when doing experiments in group	3.14	0.93	26.4	10
8	I can complete experiments within given time	3.16	0.69	26.4	10
11	I can identify the chemicals required for experiments	3.22	0.91	20.8	11
16	I am able to prepare chemical solutions of required concentrations	2.12	1.07	20.8	11
14	I can safely handle laboratory chemicals	2.56	1.32	17.0	12
10	I am able to identify the apparatus required for an experiment	3.34	0.83	15.1	13
12	I am able to handle laboratory chemicals	3.44	0.76	13.2	14
13	I am able to set up the apparatus as required by an experiment	3.56	0.97	9.4	15
9	I can keep accurate records of work	3.58	0.82	5.7	16

Note: Table shows, in addition to frequency, mean and standard deviation for each statement, but they were not depicted here for the whole sample. M and SD represent mean and standard deviation respectively.

4.2. Findings of the Second Research Question

The second research question indicated the reasons why students found the above-mentioned five areas difficult. Interviews for 3 chemistry teachers and FGD for 6 students were employed to find the answer to RQ_2. Thematic analysis of RQ_2 data explored broadly three major factors such as (1) students' factors (2) teachers' factors and (3) laboratory factors affecting students' ability to perform chemistry experiments.

4.3. Findings of the Third Research Question

Third research question was generated to find strategies that can be adopted to address the problems. Thematic analysis of teachers' interviews revealed that they focused on three areas including (1) students' assessment (2) training and workshop for teachers' professional development and 3) laboratory renovation to improve students' performance.

5. Discussion

5.1. Discussion of the Findings of Research Question 1

The findings for RQ_1 identified and ranked the challenges higher secondary students face in conducting chemistry experiments. Using statistical measures such as percentage, mean, and standard deviation, the analysis provided insights into the frequency and difficulty level of various tasks. Statements were ranked based on the percentage of students who reported challenges, with those higher on the list representing more significant difficulties.

Clearly, the statement ‘17’ and the statement ‘18’ were the most difficult tasks for 75.5% and 69.8% of the students respectively. However, of the challenges, the statement ‘1’ was problematic only for approximately 50% of students. While the mean and the standard deviation for statement ‘17’ were 1.91 and 0.94 respectively, it was 2.08 and 1.16 for the statement ‘18’. In addition, the mean and the standard deviation for every respondent and statement were also calculated. 3.05 and 0.23 were the mean and the standard deviation for the sample respectively.

Overall, the mean score across all respondents and statements was 3.05, with a standard deviation of 0.23. These metrics highlight the general performance level and consistency of students' difficulties. This data-driven approach not only identifies specific challenges but also underscores the need for targeted interventions, such as focused training and resource allocation, to address these difficulties effectively.

5.2. Discussion of the Findings of Research Question 2

Findings of the RQ_2 identified three types of relationships with students’ laboratory performance including:

Relation between students’ factors and students’ laboratory performance: Students’ factors consisted of two variables: prior knowledge and attitude toward practical work, which align with the constructivism learning theory. Due to gap in knowledge in occurred at the secondary level, students cannot not establish connection between theoretical concepts and practical work at the higher secondary level, resulting in their poor performance. When requested to give their opinions about the reasons why students’ performance was poor in the above-mentioned areas, teachers claimed, “*Students’ practical skills at the secondary level were not satisfactory.*” They also claimed, *“students couldn’t identify simple chemicals and apparatus, e.g., test tube”, “were afraid of using apparatus”,* and that “*they couldn’t apply theory”.*

Seery (2009) investigated the importance of students’ prior knowledge and aptitude in determining the performance of undergraduate students. The research found a positive correlation between learners’ previous knowledge and performance. To reiterate the importance of prior knowledge, Bailey and Garratt (2002), as cited in Schmid and Yeung (2005), concluded that the most influential single factor about learning was what the learner already knew because it worked as a sense-making to the learners. This was further supported by Johnstone (1997), as cited in Schmid and Yeung (2005), who concluded that students tended to receive information from teachers with importance when it matched with their pre-existing knowledge; however, they tended to consider the information to be unimportant if it was not a good fit with prior knowledge.

‘Students’ attitude towards laboratory work’ was another reason which impacted their performance. From the constructivist point of view, a student with positive attitude often actively involves in the laboratory, whereas a student possessing negative mindset caused by an inaccurate assessment will disengage from the authentic efforts required for knowledge construction, complete the tasks only superficially, and lose sight of the value of self-improvement and mastery. 2 out of 3 chemistry teachers claimed, “*students didn’t take practical classes seriously”*. They also argued that students believed, *“practical chemistry is less important than theory classes”* and that *“obtaining good grades in the final examination is easy”.* Teachers criticized the assessment method and said, “*students obtained good marks* *in the practical despite not having requisite knowledge*". Obtaining a good grade in practical at secondary level despite not having requisite skills made students reluctant to do practical work. On the contrary, if the assessment were done accordingly, only those who were serious would pass or get good marks, and the rest would fail or score poorly. This was agreed by Jimaa (2011) who conducted research to find the impact of assessment on students' learning, which indicated that students' unrealistic assessment often creates problems on their achievements leading to wrong approach.

Relation between teachers' factors and students' laboratory performance: Teachers' factors were composed of teacher's demonstrations techniques, attitude and motivation. Demonstration was a major reason why students could not follow experimentations. Findings of the FGD revealed that students struggled to understand and follow teachers' instructions, and became demotivated for teacher negative feedback and comments. This is in line with the student-centered learning framework, which posits scaffolding should be coherent, regular, and, if possible, repetitive. Additionally, observation, practice and reflection should occur in close proximity. If these elements are not implemented in a timely manner, a fragmented learning cycle may result, reducing its effectiveness. Furthermore, unexpected replies and feedback from teacher can disrupt scaffolding process, ultimately leading to demotivation and a reduced engagement in laboratory work.

'Laboratory demonstrations' impacted students' laboratory performances. In FGD students claimed, "laws and principles were delivered in the theory classes long ago" and that "laboratory demonstration seemed unclear". FGD indicated, "laboratory instruction was not repeated in the practical classes". If relevant laws and principles were taught in detail before demonstrations, students would be well-prepared in advance about specific chemical changes that they were going to observe. In chemistry, demonstration is performed to illustrate a scientific concept as part of laboratory work in science education (Taylor, 1988), as cited in Basheer et al. (2016). Basheer et al. (2016) in their study concluded that teachers' demonstration significantly increased students' performance in an undergraduate chemistry course.

'Teachers' attitude and motivation were other reasons why students could not perform well in chemistry experiments. 4 out of 6 students said, "teachers *were not friendly"* and "*we could not ask some relevant questions in the laboratory though the topic was unclear".* They also claimed that teachers sometimes said, "Why *are you not good at practical work?*". If the teachers were accessible, they could ask relevant questions to get a clear picture of the topic. Studies showed that teachers' attitudes and motivation played pivotal roles in students' performance. Woolfolk (2007), as cited in Ogembo et al. (2015), concluded that teachers' attitudes and motivation helped to shape the environment of the classroom, which in turn affected students' motivation. Ogembo et al. (2015) found that chemistry teachers' negative perception of their students' abilities negatively impacted students' performance.

Relation between laboratory factors and students' laboratory performance: 'Laboratory facilities' also affected learners' performance in laboratory work. In this case, laboratory facilities refer to laboratory space and its environment. The constructivist framework aligns with the finding, which suggests that sufficient and requisite resources, e.g., apparatus, chemicals and space in the classroom considering the class size, are fundamental to performing effectively in chemistry investigation. In addition to having these resources, it posits that laboratory resources should be made accessible to all students for effective participation. The limited access to laboratory resources often hampers active learning activities, e.g., group work, reducing collaboration among members. Both the interview and FGD explored the same results. During the interview, chemistry teachers were asked to explain why students could not perform heating and cooling processes. Chemistry teachers said, "*laboratory equipment was sufficient; however, we struggled to manage practical work for large classes due to lack of enough space in the laboratory"*. Teachers also said to the investigator, *"though we created groups to manage large classes, we had to suffer from limited space in the laboratory"*. In addition, students who participate in the FGD claimed, "*We could not take part in the laboratory work as the laboratory space was not sufficient for us"*.

Laboratory instructions and demonstrations were shown in a medium-sized room in which approximately 75 students, who were working in groups consisting of 10-15 members, took part in the investigation. Since it was difficult for every member of the groups to get full access to experimentation, they barely gained hands-on experience. Consequently, students often remained unclear about the particulars of experiments. The result agreed with the findings of the work done by Olubu (2015), who investigated the impact of laboratory learning environments on students' performance. It recommended increasing government funding so that institutions can be fully equipped with the necessary resources.

5.3. Discussion of the Findings of Research Question 3

The findings of the RQ_3 suggested the strategies that can be taken to improve students' laboratory performance. Professional development initiatives such as training and workshops foster constructivist practices as they allow teacher to take into account their existing expertise, promoting growth mindset. Consequently, they update, upgrade their skills and reflect accordingly in their laboratory practices, which in turn, increase student engagement and collaboration. Moreover, sufficient fund allocation ensures laboratory resources and empowers teacher and student to actively participate in the chemistry laboratory teaching-learning process. When asked, all teachers said, *"Training and workshops are very important for teachers' professional development"*. In a follow-up question, why do teachers require training and workshops? They replied, *"Teachers will be updated with the latest scientific invention which in turn will motivate them."* 2 out of 3 teachers criticized the importance of assessment. They said, *"we should be careful while giving marks to our students in the final examination"*. Since most members in FGD reported that laboratory space was uncomfortable for them. In a question on how to improve the laboratory environment, teachers said, *"funding should be increased to ensure the quality of the laboratory environment"*.

Fuller (1985) conducted a study to identify the strategies that can be applied to improve school' learning environment. It concluded that professional development training for teachers could improve the scenario. Authentic assessment reflecting students' actual ability was very important for the teaching-learning process (Uddin, 2024), especially in science (Rahmawati & Koul, 2018). Rahmawati and Koul (2018) carried out a study to identify the factors affecting laboratory learning environments and concluded that laboratory space was a vital component for quality laboratory work in addition to other findings.

Consistent with (Bailey & Garratt, 2002; Basheer et al., 2016; Woolfolk, 2007; Ogembo et al., 2015; Stăncescu & Drăghicescu, 2016; Olubu, 2015; Rahmawati and Koul 2018), the study confirms that the factors such as student's prior knowledge and attitude, teachers' instructional practices and demonstration techniques, group investigation, authenticity of assessment, laboratory resources, and laboratory funding allocation had significant negative impacts on chemistry laboratory teaching-learning process, resulting in student mediocre performance in laboratory work.

6. Conclusion and Recommendations

This section presents a summary of the work with a relevant discussion of the findings. While it provides information on implications and shortcomings, it also illustrates the areas that are worth exploring in the future.

Practical work has been indispensable for teaching and learning chemistry. It helps students to achieve hands-on experience by building connections between theory and the real world. Conducting chemistry experiments was a long-standing issue for higher secondary students at this government college. The analysis of the previous years' academic results revealed that students' overall performance was mediocre in chemistry due to poor marks in laboratory work. There have been several studies to identify factors negatively influencing students' laboratory skills at the secondary level; however, very few studies were attempted at the college level, particularly in the context of Bangladesh.

The aim of this study was to explore factors resulting in higher secondary students' ability to perform chemistry experiments. The study used a combination of qualitative and quantitative methods, with the target population being 300 higher-secondary female students and 3 chemistry teachers at a government women's college. The sample to find the answer to the RQ_1 was 50 students and 3 chemistry teachers. Both random and purposive sampling techniques were employed to represent the target population. The data were collected using a questionnaire, interview protocol, and focus group as the RI_S. The questionnaire was administered to 50 students and 3 chemistry teachers to find the answer to the RQ_1. The findings of RQ_1 were used to find the answer to RQ_2 and RQ_3, where a focus group and an interview protocol were used for 6 students and 3 teachers. For RQ_1, descriptive statistics and thematic analysis were used for RQ_2 and RQ_3. Descriptive statistics was employed to find percentage, mean and standard deviation of the statements and of the sample. Mean and standard deviation for every response and statement were calculated. 3.05 and 0.24 were the mean and standard deviation of the sample, respectively. From designing instruments to data analysis, all steps were completed with great care to ensure the reliability and validity of the study.

Overall, the study found five major challenges that students faced during chemistry laboratory investigations. Difficulties faced by students were performing the heating and cooling process, applying theories, making predictions, and following safety rules. The difficulties were caused by three major factors such as students' factors, teachers' factors and laboratory factors. It also found that training and workshops for teachers' professional development, students' assessment, and sufficient funding can be useful strategies for addressing the problems.

6.1. Implications for Practice

The findings of the study provide guidelines for administrators, teachers, and students at this institution. Firstly, by being informed about students' prior chemistry theoretical concepts and practical skills, such as heating and cooling techniques, teachers will be better able to provide effective and timely laboratory instructions and demonstrations to facilitate meaningful group work. Secondly, scaffolding will be more effective when teachers are aware of students' learning needs. Thirdly, since student motivation decreases due to negative comments and feedback, teachers are more likely to provide constructive feedback and authentic laboratory assessments, resulting in a congenial learning atmosphere. In turn, this increases student engagement and collaboration. Most students, including those who were not initially serious, will become aware of the importance of practical work for their final grades and careers in chemical fields.

Furthermore, increasing fund allocation by the relevant ministry for laboratory resources often becomes quite challenging for a developing country like Bangladesh unless supported by accurate and relevant data. This research will inform the college administration and, consequently, the ministry about the current state of laboratory resources and the need for teachers' professional development initiatives. The administration will be able to provide relevant information to higher authorities, enabling them to increase fund allocation for equipping teachers with necessary laboratory resources, such as apparatus and chemicals, and offering requisite professional development programs, such as training and workshops, to improve the teaching and learning process.

Therefore, educators and policymakers can take appropriate measures to improve chemistry education practices at the higher secondary level, particularly practical work, in Bangladesh. Overall, this research can be a valuable addition to the current body of knowledge on chemistry laboratory learning, especially in the context of Bangladesh.

6.2. Limitations of the Study

The study was conducted among a small group of chemistry teachers and students in a higher secondary setting, may have limited generalization. Due to the small sample size, the findings might not accurately represent the views and experiences of a larger population of chemistry teachers and students. Additionally, the study's focus on higher secondary education may not reflect the unique challenges and perspectives of students studying chemistry at the tertiary level. Finally, the study's ability to explain only a small portion of the variance in students' understanding of chemistry concepts suggests that it may not provide a comprehensive understanding of the factors influencing their learning.

6.3. Recommendations for Further Research

Future research could explore the factors determining students' laboratory skills on a larger scale in different contexts, such as first-year undergraduate chemistry students, across diverse educational settings that include a mix of government and non-government institutions located in rural, urban, and suburban areas. This approach would allow for a more representative understanding of the challenges and opportunities faced by diverse students across different educational settings, particularly those from remote areas of Bangladesh. Additionally, investigating the relationship between students' performance in chemistry practical work and teachers' communication skills could provide insights into how effective teacher communication enhances students' laboratory experiences. Finally, examining how these factors differ between simulated online and face-to-face chemistry laboratory work would contribute to understanding the unique challenges and benefits associated with each approach. This would enable educators and policymakers to take pragmatic steps toward improving chemistry laboratory teaching and learning practices in Bangladesh.

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Appendix 1

Factors Affecting Higher Secondary Students' Ability to Conduct Chemistry Experiments

Questionnaire for Students

Section A: Personal Information

Place a checkmark (√) in the appropriate box.

1. Gender: Male ☐ Female ☐
2. Class: HSC 1st Year ☐ HSC 2nd Year ☐
3. Religion: Islam ☐ Buddhism ☐ Hinduism ☐ Christian ☐ Others ☐
4. Nationality: Bangladeshi ☐ Others ☐

Section B: Students' perception of their ability to conduct chemistry experiments

Indicate how well you can do each of the following statements, and please rate your ability on the five-point scale:
1 = Very week
2 = Week
3 = Average
4 = Good
5 = Very Good

Serial No	Statement	1	2	3	4	5
1	I can follow appropriate safety rules for an experiment					
2	I can apply theory when doing a practical work					
3	I can follow the procedure of an experiment					
4	I am comfortable when doing experiments in group					
5	I can make accurate observations					
6	I am able to make accurate interpretations					
7	I can make appropriate predictions					
8	I can complete experiments within given time					
9	I can keep accurate records of work					
10	I am able to identify the apparatus required for an experiment					
11	I can identify the chemicals required for experiments					
12	I am able to handle laboratory apparatus safely					

Serial No	Statement	1	2	3	4	5
13	I am able to set up the apparatus as required by an experiment					
14	I can safely handle laboratory chemicals					
15	I can mix up hazardous chemicals required for an experiment					
16	I am able to prepare chemical solutions of required concentrations					
17	I can perform heating processes					
18	I can perform cooling process					

Appendix 2

Factors Affecting higher Secondary Students' Ability to Conduct Chemistry Experiments

Focus Group

(Tell me about the difficulties you faced during chemistry experiments)

1. Tell me what problems do you face when applying theory in laboratory work and why?
2. What are the difficulties you experienced about teachers' demonstration? Why do you think so?
3. Feel free to tell me what difficulties do you find regarding laboratory facilities and why?

Appendix 3

Factors Affecting Higher Secondary Students' Ability to Conduct Chemistry Experiments

Questionnaire for Teachers

Section A: Personal Information

Place a checkmark (√) in the appropriate box.

1. Designation: Demonstrator ☐ Lecturer ☐ Assistant Professor ☐
   Associate Professor ☐ Professor ☐
2. Gender: Male ☐ Female ☐
3. Teaching experience : (Less than 1 yr) ☐ (1-3) yrs ☐ (4 – 6) yrs ☐ (5 – 9) yrs ☐
   (10 yrs or more) ☐
4. Religion: Islam ☐ Buddhism ☐ Hinduism ☐ Christian ☐ Others ☐
5. Nationality: Bangladesh ☐ Others ☐

Section B: Teachers' Perception of Students' Ability to Conduct Chemistry Experiments

Indicate how well your students can do each of the following statements, and please rate their ability on the five-point scale:

1 = Very week
2 = Week
3 = Average
4 = Good
5 = Very Good

Serial No	Statement	1	2	3	4	5
1	Students can follow appropriate safety rules for an experiment					
2	Students can apply theory when doing a practical work					
3	They are able to follow the procedure of an experiment					
4	They are comfortable when doing experiments in group					
5	They can make true observations					
6	Students are able to make accurate interpretations					
7	They can make appropriate predictions					
8	They can complete experiments within given time					
9	They can keep accurate records of work					
10	They are able to identify the apparatus required for an experiment					
11	They can identify the chemicals required for experiments					
12	They are able to handle laboratory apparatus safely					
13	They are able to set up the apparatus required in an experiment					
14	They can safely handle laboratory chemicals					
15	They can mix up hazardous chemicals required for an experiment					
16	They are able to prepare chemical solutions of required concentrations					
17	They can perform heating processes					
18	They can perform cooling process					

Appendix 4

Factors Affecting Higher Secondary Students' Ability to Conduct Chemistry Experiments

Interview

(Please give your valuable opinion for the following questions related to your students' ability to conduct chemistry experiments)

1. What do you think about the reasons why students cannot demonstrate their performance when doing chemistry experiments?

2.What approaches do you think we should follow when giving instructions? Why?

3. In your opinion, what are the strategies that may be adopted to improve students' performance in chemistry practical work?