

Adopting Inquiry based approach for chemistry laboratory in India: Challenges and Opportunities

A Thesis

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by

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Certificate

This is to certify that this dissertation entitled “Adopting Inquiry based approach for chemistry laboratory in India: Challenges and Opportunities” towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research, Pune represents original work carried out by Jashika at Homi Bhabha Center for Science Education-TIFR Mumbai under the supervision of Prof Savita Ladage, during the academic year 2023-2024.

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This thesis is dedicated to my parents.

Declaration

I hereby declare that the matter embodied in the report entitled “Adopting Inquiry based approach for chemistry laboratory in India: Challenges and Opportunities” are the results of the work carried out by me at the Homi Bhabha Center for Science Education- TIFR Mumbai under the supervision of Prof Savita Ladage and the same has not been submitted elsewhere for any other degree.



Jashika

15th May 2024

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Abbreviations

CER- Chemistry Education Research
ANC- Acid neutralising capacity
BTB- Bromothymol Blue

Abstract

The thesis examined whether Indian undergraduate chemistry labs could use inquiry-based methods. Chemistry education research (CER) encourages inquiry approaches for lab education. In Indian context, the National Educational Policy (NEP-2020) promotes use of inquiry-based teaching learning processes. Currently there is very little inquiry-based learning in the context of chemistry laboratory courses and research is needed to determine the feasibility of the same, keeping in mind the challenges that are systemic in the Indian educational system like diversity of students background and infrastructure facilities.

This current research project involves designing an inquiry-based module for undergraduate chemistry labs and looking at the challenges involved in its implementation. The topic is developed in the context of estimation of antacids samples, which students can connect to their everyday lives. The module is designed to present opportunities for understanding the key concepts of the back-titration approach. The developed module was standardised for its language, questions, their sequence, difficulty levels of these questions etc. The module was given to a small group of teachers and their feedback led to further standardisation. The final module was implemented with two groups of students in different settings. The responses of the students' to questions related to back-titration were analysed in depth to understand whether the experimental module has helped in changing their understanding regarding back-titration. Additionally, the data regarding students' perception of inquiry-based lab, associated problems and opportunities was collected and analysed in depth.

The study indicates that the experimental module did help students in identifying and elucidating the reasons for usage of back titration for estimating Acid Neutralising Capacity (ANC) of antacid. In other words the experiment helps students to evolve with their understanding of the Back-titration method. The data related to students' perceptions, indicated that overall students were positive towards the inquiry-based lab. Despite facing some challenges and difficulties, students completed the entire task and were appreciative of the content and pre-lab, lab, post-lab structure of the experiment.

Chapter 1- Introduction

1.1 Background of the study

In the later part of the 19th century, chemistry lab teaching was included in college formal education to improve students' observational skills and assist them validate the concepts (Davis, 1929; Leicester and Klickstein, 1971). Since then undergraduate chemistry courses place great importance on laboratory education. The laboratory is an expensive educational environment since it requires specialised infrastructure, including equipment, chemicals, glassware, trained instructors etc (Bretz, 2019). The duration of time allocated to the undergraduate laboratory varies between 300 and 400 hours (RSC, 2015; ACS, 2015). Chemistry Education Research (CER) has asked some of the pertinent questions regarding the purpose of chemistry lab education. The literature tries to understand the significance of chemistry laboratory education, the objectives that should be pursued and are they achieved in the lab, approaches that can be adopted to align the learning with the intended outcomes etc. They have raised questions regarding what sets the laboratory apart from the lecture-based curriculum and what distinctive advantages it offers (Seery, 2020). Put simply, they question the rationale behind including laboratory work in the curriculum. The subsequent sections make efforts to elucidate some of these concerns.

1.1.1 Role of the Laboratory in Chemistry Education

There is a large literature on the purpose of practical work. Anderson (1976) makes a distinction between "science" and "sciencing" in his work, with the latter encompassing the processes that a scientist follows when conducting research. This entails using scientific knowledge to organise and carry out experiments, analyse data, draw conclusions, etc. Kirschner (1992) makes a distinction between the "substantive" structure of science, which refers to the actual information that constitutes scientific knowledge, and the "syntactic" structure of science, refers to the scientific procedures that are fundamental to the field of chemistry, encompassing the entire process from collecting raw data to drawing a conclusion. Kirschner argues that experimental work should be about teaching how to do chemistry (syntactical structure). This is achieved through experimental activities that focus on learning how to do chemistry, rather than only replicating the work of professional scientists (Kirschner, 1992; Kirschner & Meester, 1988).

Hodson (1993), argues that the laboratory should focus more on improving practical skills than learning about scientific concepts. Laboratory teaching-learning is a complex activity that aims to teach practical skills, provide students with hands-on experience, foster scientific thinking and intellectual growth, promote social interactions, and address students' affective needs (Hofstein & Lunetta, 2004; Kirschner, 1992). Reid and Shah (2007), classified the pedagogic goals and aims of the chemistry lab into four broad categories: "Skills relating to learning chemistry", "Practical skills", "Scientific skills" and "General skills". Russell and Weaver (2011) hold the view that its purpose should echo the purpose of the lecture, which in this case is to invoke interest in chemistry and motivation to learn more about it, as well as to enhance the understanding of chemical concepts and develop problem solving skills.

Some of the comprehensive reviews regarding the chemistry lab education and its characteristics are by Serry (2018, 2020, 2023). Serry (2018) provides a 5 stage framework for learning in chemistry laboratories. The framework focuses on students' progression through the curriculum supported by their previous laboratory experiences and in close alignment with the desired objective and learning in the lab. Serry (2020) argues that the most distinctive characteristic of a lab is its potential as a place where students learn how to do chemistry or the scientific skills associated with doing chemistry. Serry (2023) enlists the following intended outcomes of the chemistry laboratory instruction.

Experimental skills	Acquiring practical skills and conducting experiments: acquiring the knowledge and ability to perform a specific technique and successfully carry out an experiment.
	Data analysis and interpretation: acquiring the skills to evaluate experimental data and make informed conclusions based on the experiment's objectives.
	Designing experiments: acquiring the skills to establish a systematic approach to uncover the solution to a specific topic.
Disciplinary learning	Conceptual understanding and application of theory: acquiring knowledge of chemistry ideas through laboratory experimentation
	Academic success and competency: learning that leads to enhanced academic performance
Higher Order thinking skills	Problem-solving: acquiring the skills to tackle a challenge, typically in unstructured or research-based environments
	Argumentation: the acquisition of skills in formulating a proposition and presenting substantiating evidence, typically within carefully structured contexts
Transversal Competencies	Collaboration: acquiring the skills to effectively interact with others throughout scientific endeavours
	Communication (oral and written): acquiring the skills to effectively convey research findings in a report, with increasing degrees of proficiency demonstrated through more organised tasks.
Affective Outcome	Effective communication of learning outcomes fosters a good professional identity linked with laboratory work by assisting students in managing expectations, motives, and anxiety.

Table 1.1 Intended outcomes of chemistry laboratory education

To achieve the learning goals of laboratory education as outlined in the CER, it is necessary to understand the instructional strategies that support the achievement of those objectives. In the following section, different instructional styles will be discussed.

1.1.2 Instructional styles

The instructional strategy used for laboratory experiments governs students learning in the lab to a considerable extent. Domin (1999) provides a summary of different laboratory instructions such as expository, discovery, inquiry-based, and problem-based laboratories. The classification is based on parameters such as whether the procedure is given, the outcome is known to the instructor and whether the approach involves an inductive or deductive approach. The following table presents the details by Domin. In problem based and inquiry approaches the procedure is student generated whereas for expository and discovery style it is given to the students.

Table 1.2 Instructional style followed in chemistry laboratory (Domin, 1999)

Instructional Style	Procedure	Outcome	Approach
Discovery	Given	Known to instructor	Inductive
Expository	Given	Known to instructor and students	Deductive
Problem based	Student generated	Known to instructor	Deductive
Inquiry	Student generated	Not known	Inductive

While analysing various lab manuals for characterising the level of inquiry, Buck et al. (2008), have considered aspects such as questions to be investigated, required theoretical background, experimental design, analysis of results, its communication and conclusions. Their rubric for classifying the level of inquiry for a given lab experiment is in the following table. They have subclassified inquiry as guided, open and authentic. Thus this is a comprehensive rubric that is being used to categorise the level of inquiry for chemistry lab experiments.

Table 1.3 A rubric to characterize inquiry in the undergraduate laboratory

Characteristic	Level 0: Confirmation	Level 1/2: Structured Inquiry	Level 1: Guided Inquiry	Level 2: Open Inquiry	Level 3: Authentic Inquiry
Problem/Question	Provided	Provided	Provided	Provided	Not Provided
Theory/Background	Provided	Provided	Provided	Provided	Not Provided
Procedures/Design	Provided	Provided	Provided	Not Provided	Not Provided
Result analysis	Provided	Provided	Not Provided	Not Provided	Not Provided
Results communication	Provided	Not Provided	Not Provided	Not Provided	Not Provided
Conclusions	Provided	Not Provided	Not Provided	Not Provided	Not Provided

Confirmatory instructional style

The expository approach is economical and can be adopted in the systems that are diverse. In this approach, students follow the prescribed procedure while doing the experiment. Often in such settings, learners gain experiences with respect to the hands-on operations but are engaged with lower levels of cognition as students focus more on obtaining the correct result (Tobin, 1990). In such an approach, the results obtained by students in an experiment must align with the anticipated result. Thus expository style prioritises the validation of pre-existing knowledge, thus emphasising the substantive nature of the chemistry. The learner lacks active engagement with the content and lacks an understanding of the tentative nature of scientific explanations or the exploratory nature of research (Mauldin, 1997).

In literature there are several criticisms and arguments related to the learning in the expository style. The primary arguments and criticisms in the literature can be summarised as follows: (J. Burnham, 2019)

“The confirmation style presents the laboratory as being subservient to theory and science as a body of information which is (and can be) verified and certain” (Kirschner, 1992).

“Applying set algorithms to solve problems is not really problem solving” (Bodner, 2003)

“The goals the students have for their laboratory work (finishing early, avoiding mistakes) are different to the pedagogic aims and intended learning outcomes of the work (DeKorver and Towns, 2015) hence these objectives are not achieved” (Hofstein and Lunetta, 2004; Abraham, 2011)

The confirmatory approach emphasises the verification of concepts, following prescribed procedures, training in lab technique and obtaining accurate results. However, it does not provide opportunities to achieve many of the intended purposes of laboratory teaching such as scientific thinking, planning of experiment, result interpretation etc. As a result, there exists a disparity between the potential benefits that can be derived from a chemistry laboratory and the actual outcomes observed in expository laboratory configurations.

1.1.3 Inquiry-Based learning:

The inquiry-based laboratory curriculum addresses the issues associated with expository experiments. Compared to the traditional expository curriculum, the inquiry-based curriculum puts more focus on the student than on the manual and instructions during the laboratory (Russell & Weaver, 2011). Inquiry, as an approach was introduced to science education in the mid-twentieth century, is a versatile learning style commonly employed in science teaching laboratories. The precise definition of inquiry is not universally agreed upon due to the diverse range of forms it can take. The following two definitions can be considered for inquiry in the context of the chemistry laboratory.

1. A format designed to enable every student to work at their individual intellectual capacity and provide them with a research-like opportunity in the field of chemistry. This is achieved by letting students formulate their Problem Statements, devise their experiments, and generate their analysis and interpretation of the data gathered. (Abraham and Pavelich, 1999, p. 2)

2. Inquiry based styles can help students in framing questions that can be investigated, making careful observations, collecting data, making appropriate knowledge claims, building evidence; negotiating and understanding through discussions with peers and the instructor thus refining the ideas etc. (Hofstein and Lunetta, 2004)

Hofstein et al. (2001) claim that when inquiry-based laboratories are developed correctly, they can improve students' constructive learning and conceptual understanding. There is evidence to suggest that inquiry-based laboratory experiments are being developed in various branches of chemistry, such as physical, inorganic, organic, and biochemistry. These experiments have been found to help in the development of scientific reasoning, laboratory skills, and conceptual understanding (Rodriguez et al., 2019; Goeltz and Cuevas, 2021; Luska, 2022).

The inquiry mode of instruction has its benefits and challenges. Kelly (2005) states that the drawbacks of inquiry-based laboratory work are that teachers may experience a lack of control, safety concerns, and a greater use of class time, Concerns over unintentionally supporting student misunderstandings, and more time dedicated to evaluating laboratory assignments. Some students may experience a reluctance to take initiative and assume responsibility in the laboratory due to a combination of increased effort and cognitive processing. Using inquiry methods offers several benefits, such as the development of subject expertise, learning the scientific process, improved communication skills, increased interest, enhanced ability to explain mistakes or erroneous results, a better understanding of concepts, and ultimately, better performance compared to non-inquiry labs.

In the current study, the Level-1 inquiry based module was designed to understand the use of back titration in estimating the ANC value of antacids.

1.1.4 Pedagogical framework for students' learning in the laboratory

An effective educational approach is essential in laboratory education and science education in general. Kirschner (1992) cautions scientists who also teach to be cautious of the use of laboratory experiments in an educational environment. In the realm of professional science, researchers conduct experiments to advance the development of theories. However, in the field of educational science, experiments have several pedagogical purposes. Accordingly, the entire laboratory course must be structured within a suitable pedagogical framework. The two theories that are important for understanding students learning in the lab are the cognitive load theory and complex learning theory both of which are explained below.

Cognitive load theory

This theory was developed by Johnstone and his colleagues (1994, 2001, 2006). Johnstone et al. (1994) introduced an information processing model (analogically connected to computational operation) to depict the learning processes in the context of a chemistry laboratory. The model highlights significance of working memory and long term memory in the process of learning. It focuses on the cognitive architecture of humans, specifically the differentiation between working memory and long-term memory. Working memory has

limited capacity; this means that if a great amount of information is presented, it can overwhelm working memory. So it is important to integrate the incoming information into the existing knowledge structures stored in long-term memory, also known as schemas/schemata. As per this model the learners analyse, reorganise, evaluate, and assimilate information in their working memory while accessing their stored knowledge, abilities, and past experiences from their long-term memory, this is represented in the below figure.

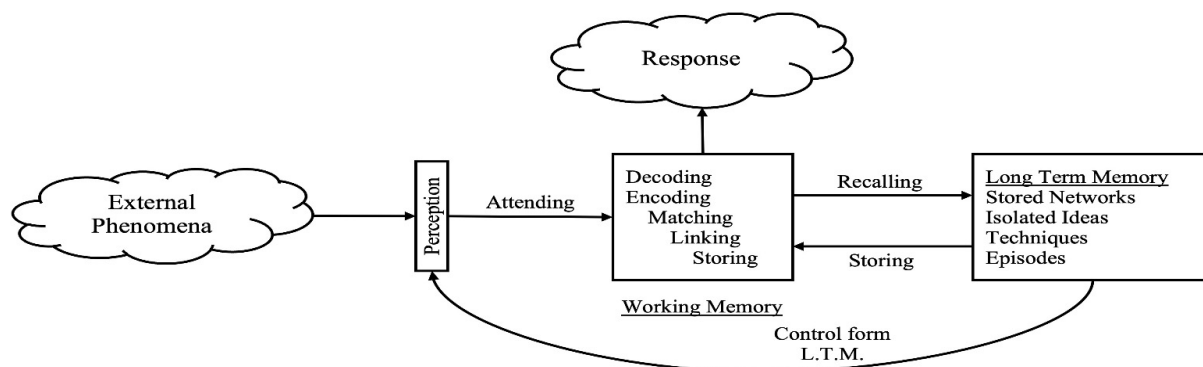


Figure 1.1 Information processing model in the laboratory (Johnstone *et al.*, 1994)

Research by Letton (1991) and Sleet and Vianna (1994) demonstrated that formal laboratory work at the university level did not yield much cognitive gains. Although they acquired practical skills and methods, they did not necessarily understand the expected theoretical context. It was clear that working memory space was occupied with verbal and written instructions, unfamiliar instruments and glassware and chemicals, observation and recording, and due to all this no reduced space was left for any form of cognitive processing. In an attempt to reduce the overflow caused by the overload, students used the written directions as a "mind-neutral" recipe (Johnstone 2006).

Sweller *et al.* (2011) argue that the goal of instruction is to enhance the amount of information retained in the long-term memory. If there have been no alterations in the long-term memory, then no new knowledge or information has been acquired.

The suggestions given by this theory is to divide the lab into three parts - pre-lab, lab and post-lab. Pre-lab assists in preparing students with the necessary background knowledge, the laboratory techniques relevant to the experiment, and encouraging learners for the laboratory activity. The delivery methods for pre-lab can include lectures, discussions, quizzes, technical videos, interactive simulations, and safety information (Agustian and Seery, 2017). Post-lab questions following the experiment should primarily address the interpretation and analysis of the data and observations collected during the experiment, as well as the analysis of errors and assumptions made during the experiment. (Serry, 2018)

Since the different aspects of the lab experiment are divided and well-spaced out, the overload on working memory is reduced. As learners are engaged in thinking about experiments comprehensively, there is an increased probability that the new information can be stored in their long-term memory. Additionally, there is a positive outcome on students' attitude towards laboratory work (Johnstone 2006).

2. Complex learning theory:

The objectives of a chemistry laboratory involve the integration of cognitive, affective, and psychomotor components for the learning process as suggested by Galloway and Bretz (2015). In all instructional approaches, the lab task assumes paramount importance; even in a confirmatory lab, students are expected to experiment by themselves, thus the psychomotor and affective aspects become important. The psychomotor aspect requires students to operate the instruments and make observations; this requires mental and physical coordination. The affective domain also gains similar relevance. It includes attitudes to science, like how confident, motivated, interested, satisfied, and joyful they are with it; as well as their scientific attitude, which includes ways of thinking about science, like being open-minded and critical, sceptical, curious, etc. (Johnstone and Al-Shuaili, 2001; Zion & Sadeh, 2007).

According to Van Merriënboer and Kirschner (2017), complex learning refers to the process of combining knowledge, skills, and attitudes in a way that involves coordinating diverse types of skills, which may then be transferred or applied in everyday situations. Complex learning requires the synchronisation of distinct skills that differ in quality. Proficient learning necessitates the application of acquired knowledge to practical situations.

What complicates learning is not the specific difficulty of any individual component, but rather the process of integrating various components in order to apply them in a new situation. Learners may have excellent expertise in chemistry or in operating a certain instrument. However, when conducting an experiment, they need to comprehend how to combine their knowledge with the experiment or how to interpret the experimental data and observations, respectively (Seery 2018).

Complex learning always requires integrated learning goals. It focuses on coordinating and integrating real-world task performance skills, not acquiring them separately. Professional scientists can perform constituent skills because they have complex cognitive schemata (organised accumulation of knowledge in long-term memory) to reason about the subject matter and solve problems. The same is challenging for students to do, they tend to focus more on the details, and often don't have the academic knowledge or cognitive ability to see patterns in their data or draw conclusions from them (Kirschner 1992).

The suggestion that this learning theory offers for facilitating learning in complex contexts is what makes it useful. Learning tasks, supportive information, just-in-time information, and part-task practice are four interconnected components that help learning in complicated situations (Merriënboer et al., 2003). By outlining the whole task to make the integration requirements more evident and by organising the difficulty level in a step-by-step, simple-to-complex manner can also help students. Giving additional information on the kinds of resources such as chemical knowledge, instrument operation knowledge, data processing knowledge, etc. which students must use when working in a complicated learning environment is also crucial (Seery 2018).

The module designed for the study takes into account the key components and suggestions offered by both learning theories.

1.2 Research Questions

The primary aim of this study is to understand the feasibility of implementation of inquiry-based experimental modules developed for undergraduate chemistry labs. For the same, an inquiry-based module for investigating the back titration method to measure the Acid Neutralizing Capacity (ANC) of antacids is developed .

The purpose of the inquiry-based module mentioned above is to offer students the chance to engage in careful observations, gather data, draw reasonable conclusions based on their observations and data, and then formulate their inferences based on evidence for the use of back-titration method for calculating ANC values of different antacid samples.

The module designed for the study takes into account the key components and suggestions offered by both learning theories. The module is divided into three parts: the pre-lab, lab task, and post-lab task. The pre-lab consists of an introductory section on antacids and questions related to prerequisite concepts. The post-lab involves analysing the laboratory data, observation and activity that demonstrates the direct titration of antacids with HCl. This facilitates students' ability to engage in systematic thinking without being overwhelmed by the amount of information. This study aims to provide information coherently starting with simpler concepts and gradually progressing to more complex ones. Considering the familiar context of antacids, it is expected that students will be enthusiastic about participating in additional learning related to the experiment.

The designed module was standardised by obtaining feedback and responses from experts and teachers prior to its trial with undergraduate students. Afterwards the module is implemented with students and the research questions described below are investigated as a part of this study.

Research Questions

1- What do students' responses indicate about their comprehension of the back-titration method gained through the inquiry-based module?

The module is designed to navigate students to find out the reasons for doing back-titration for antacid samples. The pre-lab questions cover the fundamental concepts (such as solubility, working of indicators, and antacid action) that are crucial for understanding the experiment. Observations on solubility and colour change are necessary throughout the lab experiment, as they help to connect between the pre-lab and lab work. During post-lab sessions, students are given the chance to analyse their laboratory data and observations in order to answer the questions. In the process the students need to investigate the reasons for using the back-titration method.

Students' responses indicating their understanding of the back-titration method were collected before and after the experiment. It is hypothesized that, if the anticipated inquiry has happened,

it is likely to change their conceptions which will be observed in their explanations after the experiment.

2- What are undergraduate students' perception of inquiry-based instruction in the laboratory setting?

Students from undergraduate chemistry courses are engaged with the lab primarily in an expository approach. Thus it is important to understand students' perception of the inquiry-based laboratory in contrast to traditional lab experiences. Such data is crucial to understand students' learning experiences and difficulties; how the module was received by them in the implementation process. A nuanced comprehension of students' perception is critical to bring the meaningful modifications in the module so as to enhance the learning experiences for the learners.

1.3 Significance of the study in the Indian context:

The University Grant Commission (UGC) guidelines (2022) have introduced a new framework on the undergraduate curriculum aligned with National Education Policy (NEP). It places a strong emphasis on the Outcomes-based approach to higher education. Some of the key outcomes mentioned include disciplinary learning, complex problem-solving, critical thinking, creativity, communication skills, analytical reasoning, research-related skills, autonomy, responsibility and accountability, and collaboration with others. The document also emphasizes the development of practical abilities that consolidate the interconnections between theory and practice. Additionally, the document also highlights that adopting these outcomes, necessitates a substantial transition from teacher-focused to student-focused teaching methods, as well as from passive to active/participatory teaching methods. In the context of lab education, the use of inquiry-based approaches is likely to help to develop these outcomes.

Thus, in the context of chemistry lab education it is important to develop such practical activities/experiments using different levels of inquiry and implement them in diverse setups. Such data will help in understanding the difficulties and challenges involved with implementation of inquiry based approaches in the context of lab education. The current study has made an effort to develop an inquiry based module that can be implemented in conventional lab setups of UG chemistry labs in state colleges affiliated to the University system. Efforts are made to minimise the technical demands of the module so that it is not constrained by the infrastructure facilities or lack of availability of chemicals/instruments.

The implementation study is important because students mostly have experience in expository lab classes. As a result, the experiences of students in inquiry laboratories will vary, and it is crucial to record these experiences to inform the development of lab courses that incorporate further stages of inquiry.

Chapter 2- Methodology

2.1 Research Design

The overall work done as a part of this study can be divided into the following four phases stated below:

Phase I- Choosing an experiment and standardization of experimental procedure

Phase II- Designing of the module and its standardisation through feedback

Phase III- Implementation of the final version of the module with students and data collection

Phase IV- Data analysis

The first phase involved selection of appropriate experiments suitable for UG chemistry lab course and standardising the procedure for different samples. This work was carried out at the place where the researcher was located for her project.

The second phase had two sub parts. The first subpart, included design of the module that involved development of appropriate content for the module. The content development involved introduction to the task, pre-laboratory worksheet, laboratory task sheet, and post-laboratory worksheet. The feedback forms for students' perception was also developed along with the module. In the second subpart, the designed module was validated by subject experts who are engaged with inquiry based laboratory instructions.

This was followed by implementing the module with a small group of practicing teachers (3 Female and 4 Male) who were from different parts of Maharashtra. They specialized in different areas of chemistry, had varied teaching experience and this trial was conducted as part of a capacity building workshop at Pune. The feedback from experts and teachers led to modifications with respect to language, clarity and sequence of questions etc in the module. The details of Phase-1 and Phase-2 are discussed in chapter-4 of the thesis.

The third phase included the implementation of the modified module with students. The first implementation was done at the institution where the researcher was located whereas the second implementation was done in students' own college settings (authentic) at Pune. The datasheet for both these trials is provided on the next page.

The fourth phase involved data analysis. The sample size in both settings is close to the instructor to student ratio in the lab settings for state colleges. The data was analysed in depth qualitatively so as to understand students' responses related to conceptions of back-titration and their perceptions of inquiry approach. The methodology used for analysis is explained in the subsequent sections (2.4 and 2.5) of this chapter, data analysis is explained in detail in Chapter-4 and 5 of the thesis.

Table 2.1 Datasheet for Trial-1 and Trial-2

	Trial 1	Trial 2
Month and Location	December 2023 and Mumbai (at the institute where the researcher was located)	January 2023 and Pune (in students' own college set-up)
Duration	2 days 9 hours (pre-lab -3 hours, lab- 1.5 hours, post-lab- 4.5 hours)	2 days 10 hours (pre-lab -3 hours, lab- 2.5 hours, post-lab- 4.5 hours)
Participants	2nd year BSc students 16 students (8 groups) from different parts of India	2nd year BSc students 20 students, 10 groups from a single college
Observers	2 observers	2 observers
Facilitator	2 facilitators that includes researcher	1 facilitator (researcher only)
Data Collected	Module worksheet, feedback form, Observers' notes, facilitators' notes	Module worksheet, feedback form, Observers' notes, facilitator's notes

2.2 Human Resources in the study

The study involved experts, facilitators, observers, external individuals and students. The following section gives information about these different groups who were involved with this research study.

Experts

It is important that the inquiry based module is validated through experts. In the current study the developed module was given to 3 different experts located in 3 different institutions and well experienced with inquiry-based teaching learning processes in the context of chemistry lab education. Expert-1 had 16 years of teaching experience, including 5 years of experience in chemistry outreach and teacher training. Expert-2 has more than 10 years of teaching experience and has been engaged with capacity building programs for teachers at UG level for more than 4 years. Expert-3 has 15 years of experience for conducting programs for undergraduate teachers and students. All the three experts are engaged with development of inquiry based modules for the chemistry lab. For the trial that was conducted with a group of teachers, Expert-1 was the facilitator whereas Expert-2 and 3 were observers. Additionally, the researcher herself was also an observer for this trial.

Facilitators

For implementation studies conducted with students, researcher was the sole facilitator for the second trial that was conducted at Pune. For Trial-1, researcher and additional expert (with 2 years' experience for programmes for students and teachers) were facilitators. The presence of additional expert for Trial-1 was important as the researcher herself was engaging with the process of facilitation for the first time. Prior to Trial-1 extensive discussions regarding facilitation were conducted with the expert and thesis supervisor to acquaint researcher with the process of facilitation.

Observers

In any such study, the presence of an observer is important as the observer's notes is another crucial lens for looking at the process of implementation independently. In the current study efforts were made to have observers for both Trial-1 and Trial-2. For Trial-1, there were two observers of which observer-1 was a senior retired professor with 33 years of teaching experience in organic chemistry. Observer-1 has been using inquiry based approaches and has been serving as a resource person for several teacher workshops. Observer 2 was a staff member at the institute where the researcher was located and is closely involved in a major program for science teachers at high school. The program has thrust on developing and implementing instructional material using investigatory/inquiry approaches for concepts related to science and maths.

For Trial-2, Observer-1 was from the institute where the trial was conducted whereas Observer-2 was a postdoctoral fellow involved with development of instructional material for chemistry lab at UG level, was also involved with programs for teachers and students at UG level and was from the institute where the researcher was located.

External Individuals

To validate the inferences related to students' perception data, students feedback responses were also seen by two individuals other than researcher. They were given a set of questions (refer to section 2.5) that they have to answer. These questions captured several aspects which were also analysed by researcher to study students' perceptions of inquiry-based module. The answers by the external individuals and the analysis by the researcher were corroborated so as to reduce the subjectivity by the researcher in the analysis. Of these two individuals, one was observer-2 for Trial-1 whereas the other individual (PhD student in science education with background in chemistry) was not involved in any of the trials.

Participants (Students)

For trial-1 60 Students from all over the country were selected for a chemistry camp at the institute where the researcher was located. 16 of those students were allotted for this research project. They were paired to form 8 groups and each group consisted of one male and one female. The students represented a variety of state and central universities, both public and private, located all around the nation.

For trial-2 the department announced the workshop for second-year students of a 4-year BS program. Since; at the time of trial the semester had just started, 20 students (10 pairs) attended the session on the first day. On day-2, 3 students from 3 different groups did not attend the post-lab session. However, the single student from these three groups individually completed the post-lab worksheet. Module was conducted in the college laboratory to get an idea about challenges faced for implementation of such modules in a typical college lab.

The sample was not selected by the researcher as participant groups were allocated to her. For trial-1, the researcher communicated to the organizer of the program orally that the group should be a true representative of the entire student sample participating in the program. However the researcher was not involved in any further proceedings of sample selection. The

researcher did not have access to the data related to previous academic performance of the students. Thus it was not possible to understand the equivalence of both the samples in terms of their previous academic experience.

2.3 Ethical Considerations:

In the current study participants were informed about the purpose and benefits of the study, and their queries were answered by researcher prior to the implementation. Written consent was obtained from all the participants and for Trial-2 consent was also obtained from the authorities to conduct the study. Before the implementation of the module, the participants were provided with a consent form (Appendix A) to verify that their involvement was voluntary and based on informed decision-making. It was also mentioned that students were free to withdraw from the study at any point and their involvement in the study had no impact on their college evaluation. Upon comprehending the requirements, the participants signed the form as proof of their consent. The appropriate safety precautions were followed while students were conducting their trials.

2.4 Data Analysis

Qualitative analysis is used extensively in educational research, to comprehend the actual learning experiences of students at both individual and group levels. Qualitative analysis explores subjective aspects such as interest, motivation, beliefs, perceptions, the factors that directly or indirectly influences learning processes. In the current study the research questions aimed at understanding responses of participating students towards questions related to back-titration. Thus it was important to look at group responses in considerable detail so as to map their conceptions related to back-titration prior and post-facto to the experiment. Sample size for trial-1 and trial-2 was 16 and 20 respectively, which is similar to the instructor to student ratio in the chemistry lab, as suggested by experts and teachers.

Through a variety of data collection tools, such as structured interviews, worksheet analysis, observation notes, and thorough feedback, a researcher can gain a deeper and enriched understanding of the diversity of reasons that impact student learning. Qualitative analysis of such an extensive data presents a detailed and subtle depiction, offering valuable insights that may not be captured effectively through quantitative analysis.

2.4.1 Data Analysis for Research Question-1

This research question aimed at understanding whether and how students' comprehension regarding back-titration methods evolved. When assessing conceptual connections and thinking structures that go beyond conventional notions of right or wrong, such as in the context of back titration for this study, it is crucial to critically read and analyse individual responses. To check for its evidence is to look at how students explain their conceptions in the worksheet. The responses of the students to questions related to back titration were clustered into different categories. Thus the categories emerged from the data rather than setting them a priori. Such an

approach necessitates a thorough evaluation of all textual segments and thereafter developing themes or codes that are firmly grounded in the actual data. In other words, researcher do not fit the data in the predefined categories. This primary advantage of such a method is its reliance on the data for both the emergence of codes and their interpretation. However, such an approach necessitates comprehensive analysis of the data, which can be time-consuming and challenging, especially for huge data sets.

This approach is a bottom-up approach and is similar to a grounded theory approach. Grounded theory is a systematic and iterative method that aims to find categories and concepts within a text, which are then connected to construct a formal theoretical model. This technique is based on inductive reasoning and has been developed by researchers such as Glaser and Strauss (1967) as well as Corbin and Strauss (2008). According to Charmaz (2006), grounded theory is a collection of systematic and flexible principles for gathering and interpreting qualitative data to develop hypotheses that are based on the data itself.

In the current study, a thorough analysis of the student responses led to five emerging clusters. An iterative procedure was followed to fine-tune these clusters and two experts (Supervisor and experienced researcher in qualitative methodology) gave their feedback on the cluster to validate it. The researcher explained these clusters and her thought process to both these experts. Then these validated clusters were used to map students' responses to see how their conceptions had evolved.

2.4.2 Data Analysis for Research Question-2

The research question 2 aimed at understanding students' perception of the designed inquiry-lab module. According to Berger (2015) and Eddles-Hirsch (2015), students' perceptions are based on their overall experience and offer insight into their accomplishments. Interviews, self-reporting, the Likert scale, questionnaires, rank-order surveys, and other similar methods are used to record students' perspectives (Russell and Weaver, 2008).

After implementation of the module, a feedback form (Appendix-C) was given to the students in both the settings. The feedback form used two types of questions, namely, 5 point likert-scale (ranging from strongly disagree to strongly agree) and open ended questions. The feedback required students to reflect on the inquiry-based lab experience and then fill their answers. For both the settings, students were given a week to complete the feedback form. An additional question regarding post-lab activity was given to students in Trial-2.

Often likert scale includes both positive and negative statements. In this feedback questionnaire the open ended questions were related to later aspects such as the most challenging part, the difficulties faced, unclear part, irrelevant part etc along with the best part and learnings of the module. In other words, it tried to capture both the negative and positive perception.

The likert scale gave only one negative statement since the open ended questions captured this aspect in a more detailed manner. Allowing students to describe their responses to the open ended question gives them the freedom to express their experiences in greater detail. Such responses can help the researcher to understand students' perception in greater detail at an

individual level. However, the feedback questionnaire as a research instrument can be further standardised for future trials.

The methodology employed for open-ended questions involved coding and categorization (second cycle coding process). Coding involves the analysis and organisation of data by creating indexes or mapping data. This process helps researchers gain a comprehensive understanding of diverse data and how they relate to their research objectives (Elliott 2018). In qualitative study, a code is typically a word or brief phrase that symbolically represents a concise, significant, essence-capturing, and/or emotive feature for a section of language-based or visual data (Saldaña, 2016).

At the initial stage of coding, descriptors and low inference codes are primarily employed to condense the data. Subsequent codes might be more interpretative, second-level coding primarily emphasises pattern codes. A pattern code is a type of code that is more inferential and can be considered as a "meta-code". A pattern code is a higher-level idea that consolidates more concrete, descriptive codes (Punch, 2014).

The Categorization involves the creation of a category or thematic structure for the code list. This includes reviewing and modifying the existing codes, as well as determining the main categories or themes that include them. This procedure is comparable to Saldaña's (2013) Second Cycle coding method, in which the First Cycle codes are examined and organised into significant categories, themes, or structures.

Focused coding is one of the ways to do this, it serves as a successful link between the inductive and deductive codes that have been developed up to this point. After coding the data for initial impressions and pre-identified concepts, this coding cycle comprises searching for thematic or conceptual consistency among the data by specifically examining the codes themselves (Charmaz, 2006; Saldaña, 2013). This categorisation of codes can be based on the conceptual framework, code frequencies, and by choosing the most relevant codes for addressing their research objectives (Braun & Clarke, 2013). The distinction between codes and categories is established at the coding level. From this perspective, a category can be understood as a higher-order code. (Elliott 2018)

In this study, I started the coding procedure without predetermined codes and relied on the data itself to propose the initial codes. Afterwards, categories were identified, they required an in-depth examination of all data with their respective initial codes. Emergent codes here may include specific phrases said by participants or ideas that I, as a researcher, identified during the analysis of the entire dataset. Afterwards, the frequency of each emergent code is also counted. The significance of counting here is understanding how widespread a particular code is across the data.

2.5 Addressing issues of validity

Validity may be an issue and must be addressed when qualitative research methodology is used for research study as stated by Denscombe (2010). He advises the researcher to assess the credibility of the participants' statements and refrain from taking things at face value.

Denzin & Lincoln (2018) states that combined use of various methodological practices, empirical materials, perspectives, and observers in a single study can be seen as a strategic approach that enhances the rigour, and comprehensiveness and adds more details, richness, and subtlety of any investigation. Thus, measures taken in the current study to address the validity concerns are described below.

Research Question -1

The analysis of students' explanation related to back-titration was juxtaposed with the notes obtained from the observers and facilitators. As explained in subsection 2.4.1 an iterative procedure was followed to fine-tune these clusters and two experts (Supervisor and experienced researcher in qualitative methodology) gave their feedback on the cluster to validate it. Additionally, observers' notes and facilitator's notes were also considered to understand how students went through the process of inquiry. This process of comparison of data obtained from students with that from observers and facilitators is known as triangulation. Thus the evidence is arrived at using data from multiple sources, hence minimising the possibility of arbitrary connections and systematic biases at researcher end. Such a process enables one to get an improved understanding of how generic the emerging explanations/evidence are (Maxwell, 2012).

Research Question -2

The categories emerging from the open-ended feedback responses were discussed with the supervisor and also shown to the expert. The students' feedback responses were independently looked at by two other individuals. One of the individuals participated as an observer in Trial-1, whereas the other individual did not have any involvement with the study, but has a chemistry background. After reviewing the responses, they were asked to provide their opinions on the following questions individually for each trial.

1. Which parts of the module were liked by students?
2. What are the challenging aspects of the module for students?
3. What have students learnt from the experiment?
4. How do the students perceive their learning in this module?
5. What are the differences students observed in this module compared to regular lab?
6. What are the key takeaways from the overall student's feedback?

Optional: what differences have been noticed between Trial-1 and Trial-2?

Their responses to these questions helped to validate the conclusion that was drawn by the researcher. Such a step is again similar to triangulation as the conclusion was arrived at by seeing the agreement between the interpretation by three different individuals.

Chapter 3- Design of the Module

The current chapter will present details about the inquiry based design of the chosen experiment. It will elaborate on the rationale for selecting the experiment, the structure and content of the module, feedback received from the experts and teachers that lead to further modifications to its current design. It also presents learning objectives of the current module and how the inquiry related elements were incorporated into back-titration. The final version of the module is also compared with the conventional experimental write-up of the same experiment.

3.1 Selection of the experiment

To arrive at the experimental area for developing the inquiry-based module, the titration domain looked promising as these experiments are an integral part of any undergraduate chemistry lab course. Furthermore, the key prerequisite chemistry concepts required for the titration are included in the chemistry curriculum at the undergraduate level. The titration domain was thus chosen, and it was also preferred that the selected experiment has least technical demands and provides a familiar context to students. These factors increase the chances that selecting an experiment from this field can result in the incorporation of such an experiment as part of a laboratory course.

So the researcher looked at experiments related to the titration domain. Researcher's own institute lab manual covered titration experiments in the area of acid-base chemistry (including pH and conductivity meters), complexometry, redox (Iodometry/permanganate) and precipitation titration. Refer to Appendix -D for details of the experiments.

With all the above mentioned considerations, researcher chose analysis of antacid samples as an area for developing the inquiry based module. The reasons for selecting this module are as follows:

1. For analysis of antacid using acid-base chemistry the back titration method is used. This experiment provides learning opportunities to comprehend and deduce the reasons why this method is preferred over direct titration. Thus such a situation can be harnessed cognitively to reflect the choice of back titration for the estimation of antacid.
2. Most of the students are generally familiar with antacid samples and may have used them when experiencing symptoms of acidity. Such experience provides a relatable context for students and can serve as a motivating factor for them to study the chemistry of antacids.
3. There are varieties of antacid products available in the market in different forms like powder, chewable tablets and oral suspension/liquid. They contain various types and amounts of active antacid ingredients, like hydroxides and carbonates of different metals. Hence; it will be interesting for students to observe how the efficacy of these samples differ and the same can be related to prescribed dosages. Such titration

experiment is similar to the pharmaceutical trials, allowing students to explore the application-based area of chemistry.

4. This experiment involves related theoretical concepts such as solubility of sparingly soluble salts, variation in such solubilities as function of pH, working of indicators and stoichiometric calculations involving concepts of moles.
5. The required chemicals for such a titration (HCl, NaOH, Indicators) and glassware (Burette, conical flask, funnel, measuring cylinder, hotplate) are easily available in regular colleges making it more feasible for implementation.
6. The analysis of antacid samples also gives an opportunity to compare areas like estimation of samples using acid-base titration or complexometric titration. The instrumental techniques such as colorimetry can also be used for such an estimation. Thus it is a comprehensive theme for performing different types of experiments and understanding their merits and demerits.

3.2 Structure and content of the module:

The module was designed as a Level-1 inquiry. Even though this module can be developed with higher levels of inquiry the researcher chose to use level-1 as she did not have any experience related to implementation of inquiry based modules for students with a background in traditional laboratory environments. It was important to gather first hand experiences regarding the challenges and the difficulties at level-1 inquiry, for such an experiment prior to developing the module for higher level-2 of inquiry.

The researcher adopted pre-lab, lab and post-lab format as suggested by pedagogical frameworks on learning in lab. The details of the structure and the content of the developed module are discussed below.

Pre-lab

The write up, designed as a part of pre-lab presented introduction, gave adequate background information on antacid samples (tablets and suspension) containing weak bases such as hydroxides and carbonates. Initially students were asked to list the names of antacids they have heard or consumed to understand their familiarity with the antacids.

The purpose of this question was to make students comfortable with the current experiment. Then a table was provided presenting the composition of different antacid samples along with the functions of antacid active compounds and non-antacid active components.

Students were expected to write the chemical reaction between antacid and HCl to comprehend how antacids work in the stomach when consumed. Students reflected on how the antacid efficacy differs due to a) the various types of active compounds and b) the amount of these active ingredients in given antacid samples.

The above questions helped to initiate discussion on antacid efficacy parameters such as acid consumed in the reaction with antacids, estimating time duration for relief etc. Students were

asked to give an activity (with their existing understanding) that will help in measuring any of these parameters numerically.

The next set of questions were related to pre-requisite theoretical concepts such as solubility of antacids containing $\text{Mg}(\text{OH})_2$ and $\text{Al}(\text{OH})_3$ in aqueous solutions and when HCl is added to such solutions. Choice of appropriate indicator is another crucial concept in acid-base titrations. The structure of the Bromothymol Blue (BTB) indicator was presented and students had to identify the acidic proton and the structural changes it undergoes after deprotonation.

The UV-Vis spectra of BTB at low and high pH were provided for students to determine the colour of its protonated and deprotonated forms. The questions were designed to help students see how the pH, structure, colour and UV-Vis spectra of an indicator are related. For example: To understand the wavelength shift of the visible spectra, it was crucial to connect the structural change and pH. Additionally, questions related to calculation of the pH range for the colour transition of the BTB indicator based on its pK_a values were included. This can help students to understand how the pH range of an indicator is determined.

The next set of questions were prediction based. Students predicted which sample would exhibit greater ANC value of the experiment prior to performing it. Another question on the suitability of back-titration is asked to comprehend students' rationale before conducting the experiment. Responses to these questions reflected their understanding prior to performing the lab task.

Initial draft also included demonstration of a situation where the antacid sample is directly titrated with HCl . However, after receiving feedback from teachers, this demonstration was shifted to post-lab where students were expected to do careful observations with respect to colour changes and explain them.

Lab task

During the lab, students performed back titration experiments with two different samples (Sample-1 and Sample 2 on page no. 67). Each group performed at least 6 titrations, which included blank titrations and back titrations for each sample.

Students were asked to keep a record of their observations regarding the solubility and color of sample solution after addition of HCl , after boiling and during the course of titration with NaOH . They were also suggested to take the photos at different stages of the experiment. These photographs served as observations that can be used as cues to relate it to the questions in the pre-lab later. A table is provided in the lab task sheet for recording the observations.

Post-lab:

The post-lab questions are primarily related to observations of the lab work and calculation of ANC values. Students are required to identify and record the chemical species present in the flask at three distinct stages of the titration process. Such a record is important to understand the reactions that are taking place during the course of titration.

The ANC value calculations were done by students by solving calculations related to blank and back titration. They also needed to calculate the dosage that they will be prescribed to bring down the acidity levels in the stomach for the range given in the question. The purpose of this question is to provide an opportunity where students use their own calculated ANC value to a real-life situation

One of the post-lab questions presented some situations with minor differences in the procedure to students and they were asked to relate how the titre value is affected for a given situation. The purpose of this question was to have the learner reflect on the procedural protocol of the experiment.

The question related to the purpose of back titration was once again included in the post-lab to understand students' comprehension after the experiment. After demonstration of the direct titration, students were again given the questions related to back-titration. The purpose of repeating the same question in pre-lab, post-lab and after lab experiment and again after activity was to track changes in students' understanding related to back titration. (However, for trial-2 due to constraint of time, this question was given as a part of pre-lab and post- activity only).

To extrapolate the understanding of back titration a question was asked regarding direct titration. The question was divided into two parts: a) the procedural modifications required for direct titration and b) the expected observations during direct titration. The purpose is to enable the reflection of pre-lab activities which involve a demonstration of direct titration and the lab experience of back titration. Based on this reflection, students are asked to determine the likely outcome of direct titration and why it is not suitable. The question demands them to convert their theoretical understanding to the possible practical observations in experiment.

For the analysis of lab data, comparison of various parameters such as solubility, ANC value, mass effectiveness, and dosage of two samples were done. We also asked questions about why certain parameters differed, whether there is any correlation among the listed parameters, and what are the differences in the action of antacid tablet and suspension. The purpose of this analysis is to understand the importance of ANC and its relationship to dosage and antacid action.

Last part of the module included hypothetical situations related to antacids, students are asked to decide between direct or back titration to calculate Acid Neutralising Capacity of antacids. The purpose is to assess students' ability to apply the understanding of back-titration gained to new unfamiliar situations.

3.3 Expert's Feedback

The initial draft of the module was reviewed by three experts. The feedback questionnaire given to them consisted of likert type questions as well as several open ended questions (Appendix-B). One of these experts was a facilitator when this draft was implemented with a small group of teachers whereas other two experts acted as observers for this trial. One expert submitted

the feedback prior to the implementation of the module with teachers whereas other two experts submitted their feedback after the implementation.

The experts appreciated different aspects of the module. They valued the context of the experiment. The pre-lab questions covered concepts related to experiment comprehensively. The experts felt these questions will help students to revise prerequisite concepts, thus preparing them well for the experiment. The experts agreed that the concepts covered in the experiment were important, and there is a considerable overlap with the UG chemistry lab curriculum.

They further appreciated the question related to the indicator, structural changes it undergoes, calculation of pH range and correlation between colour and structural changes of the indicator. The experts felt that the pre-lab questions are designed to break down concepts into smaller chunks to facilitate their assimilation.

With respect to post-lab, two questions were appreciated the most by the experts, the first that presented different scenarios affecting the titre value was appreciated the most by the experts and the second was correlating the ANC with the doses related to the analysis of the lab data, including correlations drawn between parameters. They opined the difficulty level of questions that were posed for pre-lab and post-lab varied from moderately difficult to challenging. However overall no major changes with respect to questions were suggested by the experts.

They also indicated that the module was fairly long and thus there was a need to allocate sufficient time for pre-lab, lab and post-lab. They also felt the language of some of the questions could be simplified. In response to the challenging aspects of the module, experts mentioned the questions on coming with an activity to measure different factors related to antacid action, drawing the structure of indicator, analysing the lab data, the effect of procedural mistakes on titre value, even though most of these questions were also appreciated by them.

In particular, using the experience of back-titration appropriately to understand why direct titration cannot be used was perceived as the most challenging part of the module. Even though the module provided sufficient background information, the experts felt that there was a scope to present information so as to enhance the overall clarity of the module, additionally the experts felt the module is extensive and thus will require sufficient time.

The notes obtained by two experts who were observers for the trial conducted with teachers strongly recommended shifting the demonstration from pre-lab to post-lab as it was confusing for the teachers. They also suggested simplifying the language and the sequence of the subparts of the question related to calculating ANC. Overall, there were no other major changes suggested by the experts.

3.4 Teachers' feedback to the module

The same feedback form (refer to Appendix-B) filled by experts was given to teachers after implementation of the module with a few additional questions. The additional questions were related to their perception of learning through this module, the unclear part of the module,

difficulties that they faced and their opinion whether the module is implementable in their own college set-up. The written responses to feedback form is summarized below.

The responses to likert scale questions indicated that all teachers agreed that the concepts covered in the module were crucial and had overlap with UG lab curriculum. Regarding the language of the questions, the responses were mixed. Some teachers felt that language was easy whereas others felt that it was relatively difficult. As these teachers came from different parts of Maharashtra the mixed response about the language is not a surprise. They too opined that the module was relatively lengthy and moderately difficult.

According to the teachers, the best parts of the experiment were the discussion of pre-lab and post-lab questions. Individually they appreciated different aspects of the module like questions related to theory of the indicator, the overall script of the experiment, the lab work, analyzing lab data, and arriving at conclusions.

Teachers acknowledged the importance of several factors for a meaningful lab experience for example overall discussion, understanding pre-requisite knowledge of the experiment, use of analytical thinking and relating the experiment with relevant concepts. They compared their experience with a regular lab and pointed out that they were more engaged and interested throughout the entire process. Additionally, they learned all aspects related to the experiment including theory, procedure, and calculation in detail. Thus overall they were more aware of what they were doing.

When asked about the challenges they faced, some teachers pointed out that pre-lab and post-lab questions required a basic understanding and knowledge of different aspects of chemistry. They also felt that the calculation part could be simplified.

When asked about the irrelevant part of the experiment, four teachers indicated no deletion while the rest opined that a few questions on indicators, designing of activity for measuring antacid action, and observations related to direct titration can be considered for deletion. When asked about unclear parts, some teachers suggested that words such as "titration process" and "chemical species," can be simplified or explained.

Regarding potential difficulties students may face with this module, teachers mentioned that calculations may be challenging for some students, and the length of the module may be overwhelming for those who are not accustomed to such experiments.

Six teachers out of seven opined that this module can be implemented in their own college set-up however, they also mentioned some constraints, such as not having the freedom to add the module and time. They suggested conducting 1-2 experiments per semester similar to the current module, which will be an extension experiment. They suggested some questions of the module can be given as a take-home assignment to the students so as to optimize the time spent in the college lab.

3.5 Modifications in the module

The initial draft of the module was modified based on feedback from experts and teachers, experts' observation notes, teachers' module worksheet responses and researcher's own notes during the implementation trial with the teachers.

The details of modifications are discussed below. Please refer to the final module in Appendix-E for the specific questions.

Enhanced clarity of the questions

Some parts of the module were simplified for language so as to enhance the clarity of the questions or text. The second question of pre lab was modified and the exact amounts of active antacid components were explicitly stated in question 2.

Regarding Question 3 of the pre-lab, the discussion of how various factors can be measured through activity was not focussed specifically on antacid samples and it included several general aspects. Therefore, a following additional statement about measurement was included in the question, "We can use a chemical analysis to get a numerical value that is related to the action of the antacid. In this way, their actions can be compared and studied systematically."

The Question-6 of post-lab was reworded from *change in titration process* to *change in titre value of NaOH*.

The written answers to the question related to back titration in post-lab indicated that the observations during the titration and direct titration demonstration are not effectively correlated to the reasoning.

Thus the format for presenting answers was changed and a two column table was introduced, the columns were titled as reasons and observations. Additionally, the following line was also included in the question- *Please write the experimental observation to support your reasons; if you say it's because of reason 'A' explain how you conclude it from the observation of 'A' during titration.*

Sequence of the question

For the question- 5 in pre-lab the initial sequence involved drawing the structure of the indicator for deprotonated form followed by questions related to UV/vis spectra of the indicator. Somehow, it was observed that the teachers struggled to draw the structure of a deprotonated form of indicator.

Thus the sequence of these two questions was reversed. Additionally, a cueing question that draws attention to increased conjugation for deprotonated form was also added. (Refer to part (ii) of question 5a in pre-lab).

The questions related to ANC calculation in post-lab were also simplified. The similar type of calculations involving molarities were grouped together as one subpart of a question. The question related to mass effectiveness was separated and asked later.

One of the major changes was that the demonstration activity for direct titration of antacid samples with HCl was shifted from pre-lab to post-lab as it was strongly recommended by experts as well as teachers. They felt that the purpose of this demonstration can be unclear to students when it is a part of pre-lab. In fact, teachers felt that this demonstration in pre-lab leads to confusion as the main experiment involves back titration. Researcher, while agreeing to this fact, felt that placing this activity in post-lab may help the students to use their experience of back-titration for analysing the difficulties and problems faced during direct titration.

The initial demonstration involved observations related to two different indicators for two different antacids samples along with controls. The number of observations was also putting a cognitive load. So the activity was modified where only one indicator, two samples and controls were used. An additional question was added prior to the demonstration and it was related to pH change in weak base- strong acid titration.

The demonstration involved adding a few drops of HCl to an antacid sample containing indicator and students were expected to observe the changes in the beaker carefully. They were expected to imagine a scenario that can happen if the titration is continued and were asked to answer a question: *Do you think it is possible to directly titrate the antacid sample with HCl? Explain why/why not.* The researcher changed this question to *What will be the likely observations at the end-point in direct titration? Explain your reasoning.*

In researcher's opinion, this question tries to present the scenario at a fundamental level and can be answered easily by students as it relates directly to the observations made in the activity. Once this is done, they can think further and reason out the problems in direct titration.

Deleted questions

The initial draft also had a question related to antacid samples containing carbonates. The question asked to reflect how the procedure related to sample preparation may have to be modified. However, this question was a stand-alone question and thus was deleted as the length of the module was significant.

3.6 Comparison of the module with conventional lab format

This section makes an effort to compare the final version of the inquiry module with its write-up in conventional setup. Such a comparison is useful in understanding both these formats. The following table presents the comparison of both these formats.

Table 3.1 Comparison between regular lab and inquiry-based lab.

Parameter	Lab experiment write-up (Conventional lab)* IISER lab manual.	Inquiry based module (Developed for the study)
Aim	Given	Given
Theory/Introduction	Short-description about antacids, mention of back-titration to calculate ANC	Information about different antacids and its components, four questions related to antacid reaction with HCl and their efficacy
Pre-lab	Oral instruction/discussion on the theory of the experiment.	Revision of concepts through questions on solubility of active ingredients under different pH, theory of acid-base indicator, use of back-titration and predicting ANC
Post-lab activity	Not applicable	Demonstrates scenario of direct titration of antacid samples
Procedure	Stepwise detailed instructions, with explanations at specific points	Stepwise instructions, observations related to solubility and colour changes during sample preparation and course of titration to be noted
Post-lab	Formula for ANC calculation is stated	Questions related to reflections on what happened in lab, calculation of ANC (direct formula not given) and making conclusions, predicting the effect of certain procedural step on titre value, reflection on back-titration method

The main difference between the two formats was that in the inquiry based module both the pre-lab and post-lab consisted of several questions that presented opportunities to discuss the theoretical concepts, observations, significance of procedural and data. Since, the pre-lab and post-lab involved discussions about several questions, the time allocated for both these sessions was significantly more as compared to regular lab. Overall, the inquiry module made efforts to present opportunities for students to reflect and understand use of back-titration for ANC calculation.

Navigating students through the inquiry process

The inquiry based module was focussed on making careful observation and interconnecting it to theoretical concepts and reasoning. The most significant component of this module was to navigate students through back-titration as the main inquiry. It was important that students gain experience about the back-titration as well as direct-titration. Both these aspects were part of

the module, direct-titration scenario as demonstration activity and back-titration as the lab experiment. These experiences provide students with opportunities to examine, compare and infer the rationales behind the suitability of back titration over direct titration for antacid samples containing hydroxides active ingredients.

Students' understanding was measured at three different stages in the module, it helped to track how the understanding has evolved throughout the lab. The stages are written below.

Stage 1- Theoretical discussion

Stage 2-Theoretical discussion & Back-titration Observation

Stage 3- Theoretical discussion & Back-titration plus Direct titration observations

While designing the module special emphasis was given on providing scaffolds in terms of sufficient background information, cueing, relevant questions and key observations to the learners at different stages of the module.

3.7 Learning objectives of the module

The primary learning objectives of the final module are related to the advantages of the back-titration method and the importance of ANC for measuring effectiveness of antacid.

For pre-lab, the learning objectives were related to solubility of active ingredients of antacids and theory of acid/base indicator. The post-lab had a thrust on the calculation of back-titration, importance of procedural steps.

Pre-lab

- To determine the solubility of the active component in the antacid and to understand how solubility is affected by the addition of HCl.
- To determine the colour change of the acid-base indicator and its correlation with structural changes at various pH levels
- To predict the sample with higher ANC value

Post-lab

- To identify the chemical species present in the reaction flask at different stages of back-titration.
- To calculate the ANC value of antacid samples using the back and blank titre value.
- To correlate ANC value and dosage
- To determine the effect of procedural step modifications on titre value of NaOH.
- To decide the suitability of back titration and direct titration for determining ANC values for different antacids (including hypothetical situations).

Chapter 4- Students worksheet responses and its analysis

The current chapter will present the responses of the students from Trial-1 and Trial-2. As explained before, Trial-1 was done at the institute where the instructor was located whereas Trial-2 was done in students' own college set-up. The sample size for trial-1 was 16 (8 pairs) and for Trial-2, it was 20 (10 pairs). The students of Trial-1 as well as Trial-2 were 2nd year BSc students. However, the participants for Trial-1 were from colleges located in different parts of India whereas students from Trial-2 came from the same geographical region. The data included written responses of the students to pre-lab worksheet, lab task sheet, post-lab worksheet and feedback questionnaires. Additionally, there were observers' notes and facilitator's notes. The analysis of data related to research question-1 is presented first followed by analysing students' responses to various other pre-lab and post-lab questions. The data analysis for research question-2 is presented in the next chapter.

4.1 Students' comprehension of Back-titration

The research question-1 of the study was "What do students' responses indicate about their comprehension of the back-titration method gained through the inquiry-based module?" As explained earlier, students' answers to the question related to back titration were asked at three different stages of the experiment. The rationale for collecting the responses at three different time intervals was to track students' understanding about the back-titration method.

4.1.1 Defining Clusters

As explained in section 2.5 the clusters were identified based on the actual responses (bottom-up approach similar to grounded theory). The initial clusters were refined with comments from an educational researcher, who was not a part of this study. The clusters used for final analysis of responses and their description is presented below.

Table 4.1 Framework diagram of Clusters

	Correct Reasons	Correct Observations	Correct Correlation	Remarks
Cluster-1	✓	✓	✓	Observations are correctly correlated
Cluster-2	✓	✓	✗	Observations are not correctly correlated
Cluster-3	✓	✗	✗	No observations
Cluster-4	✗	✗	✗	Invalid explanation
Cluster-5	✗	✗	✗	Incorrect explanation

The following clusters are described in elaborate detail below.

Cluster 1: Theoretical explanations correctly correlated with experimental observation in the explanation - such responses will have correct explanation, observations and correlation between the explanation and observations.

Cluster 2: Theoretical explanations partially/not correlated with experimental observation in the explanation- such responses will have correct explanation, observations are written but partially correct or no correlation between the explanation and observations is written.

Cluster 3: Theoretical explanations in isolation without any experimental observation in the explanation - such responses will have the correct explanation, but without any experimental observations.

Cluster 4: Possible but invalid theoretical explanation- such responses provide possible theoretical explanations which are conceptually correct but don't apply to the back titration of antacid.

Cluster 5: Incorrect or irrelevant explanation - such responses provide incorrect explanations.

There is a gradation associated with these clusters and hence they have a hierarchical structure, with Cluster 1 representing the most appropriate answer and Cluster 5 representing a totally incorrect answer in context of the experiment. At Stage-1 (before the experiment), no experimental observations were made so it is not possible hence the students' responses primarily will fall under cluster- 3, 4, 5. At stage-2 and 3, responses can be under any of the five clusters.

4.1.2 Mapping Students' responses to clusters:

For trial-1, the responses to back-titration questions were collected at all three stages. However, for trial-2 due to time constraints, students' responses could be collected at stage-1 and stage-3. The following figures indicate distribution of students' responses at different stages in both the trials.

Trial:1

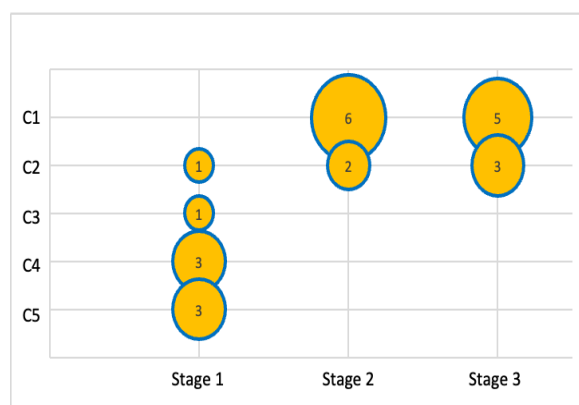


Figure 4.1 Cluster diagram in Trial-1

Trial: 2

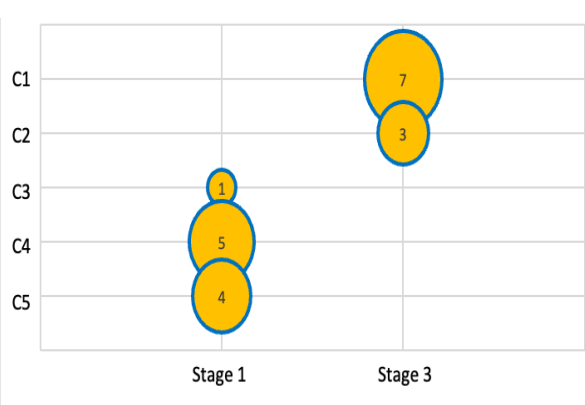


Figure 4.2 - Cluster diagram in Trial-2

The table given provides the categorization of students' responses into distinct clusters for each group at different stages in both trials.

Table 4. Group wise transition of students between clusters in Trial-1 and Trial-2.

Trial 1	Stage 1	Stage 2	Stage 3	Trial-2	Stage-1	Stage-2
G-1	Cluster 2	Cluster 1	Cluster 1	G-1	Cluster 5	Cluster 1
G-2	Cluster 3	Cluster 1	Cluster 1	G-2	Cluster 3	Cluster 1
G-3	Cluster 5	Cluster 2	Cluster 2	G-3	Cluster 5	Cluster 2
G-4	Cluster 4	Cluster 1	Cluster 2	G-4	Cluster 4	Cluster 1
G-5	Cluster 5	Cluster 1	Cluster 1	G-5	Cluster 5	Cluster 1
G-6	Cluster 4	Cluster 1	Cluster 1	G-6	Cluster 4	Cluster 2
G-7	Cluster 4	Cluster 2	Cluster 2	G-7	Cluster 4	Cluster 1
G-8	Cluster 5	Cluster 1	Cluster 1	G-8	Cluster 4	Cluster 1
				G-9	Cluster 5	Cluster 1
				G-10	Cluster 4	Cluster 2

At stage 1 for both the trials , most of the responses fall into cluster-4 and 5 as anticipated. However, one of the group responses in Trial-1 was in the C-2 cluster, because one of the students in this group communicated that he had done this experiment in his own institute. Thus this can be a probable reason why the response of this group was in the C-2 cluster.

There was no blank response in both the trials. One of the most important observations for trial-1 is that all the responses have shifted to C-1 and C-2 clusters at stage-2. At stage-3, the frequency of C-1 has changed for one group because the explanation provided by this group at stage-3 was short and did not mention the correlation between observations and reasons. However, the same group had provided a detailed explanation and right correlation at stage-2. It is possible that they may have assumed that the correlation is already stated at stage-2 and need not be repeated at stage-3. No focussed group discussion was conducted as part of this study and it's thus rather difficult to comment on their thinking process for the response at stage-3. However some of the students in their feedback form did comment that the question need not be repeated in the module. For trial-2, maximum responses fall in the C-1 cluster followed by the C-2 cluster.

The trend in the shift for explanations is observed towards C-1 in both the trials. Since, the analysis is grounded in students' own explanation on the use of back-titration method it can be established that the module has helped students in changing their conceptions regarding back titration.

4.1.3 Students actual responses from the worksheet

Students' exemplar responses are presented in the following section as it will help to understand the quality of responses in different clusters. These responses will highlight how the arguments were developed by the students to explain the back-titration method.

Cluster-1

“Reason 1: Antacids are not soluble in water hence performing direct titration of antacid solution and aqueous HCl solution can't be the measure of ANC of antacid because due to insolubility all the antacid wont react (Stage-2) and we see that even after endpoint is achieved after some time colour of the solution changes (Stage-3)

Observation 1: Solubility, In direct titration, end-point colour changes after some time.

Reason 2: the colour of solution is yellowish which changes to blue on titration with NaOH; this change can be easily detected and it is sensitive to minute concentration of NaOH hence accuracy of reading is much better in back titration (Stage-2)

Observation 2 : Ease of detecting end-point

Reason 3: In direct titration reaction b/w HCl and antacid is very slow hence; we have to heat the solution properly when we perform back-titration. (Stage-3)

Observation 3: Slow rate of reaction (Stage-3)”

(Group-1, Trial-1 the difference in the stage-2 and stage-3 answer is also highlighted)

“Reason 1: Direct titration will not give the accurate ANC as there is no perfect endpoint

Observation 1: Direct titration it was showing colour change from original colour to colour change and then back to original colour.

Reason 2: Titration can give results but will not be accurate or will not be taken into consideration

Observation 2: depending on rate of reaction, dissociation of weak Acid

Reason 3: HCL consumption based on with respect to time

Observation 3: Time required for colour change

Reason 4: In back titration the endpoint never changes

Observation 4: Accurate endpoint in back titration”

(Group-5, Trial-2)

The above responses indicate the variation in students' explanations within a cluster. Some students have chosen observation from back-titration while others chose from direct-titration for explanation. They have mentioned correct reasons which are correctly correlated with appropriate observations.

Cluster-2

“Reason 1: solubility

Observation 1: Sample one is insoluble so it takes more time

Reason 2: Endpoint

Observation 2. Endpoint in direct titration is not accurate because the colour changes to its original colour.”

(Group-3 Trial 1)

“Reasons 1: It is because of the solubility of antacid

Observation 1: This was observed in the post lab activity antacid tablet took much time to change colour completely

Reason 2: The rate of reaction is very slow

Observation 2: This was observed when antacid tablets took time to dissolve.”

(Group-6, Trial-2)

These responses state the correct observations and reasons, but do not explain how they are linked to one another.

Cluster-3

“Solubility: antacids are not soluble in water hence titrating them in aqueous solution with hcl is difficult. End-point: In direct titration determining when the reaction has completed just based on the colour won't be accurate. Buffer formation: WB+SA salt, can form buffer, which will not give accurate result.”

(Group-2, Trial-1)

“We do back titration because of many important reason firstly buffer action can be there so that is the reason for back titration. Then second could be solubility factor if antacid is soluble in water then direct titration can be done but if insoluble then need to do back titration.”

(Group-4, Trial-1)

In the above responses it can be seen that the given theoretical explanations are correct but it is stated in isolation. In other words, how theoretical reasons are applied in the current lab experiment and associated observations is not a part of the response.

Cluster-4

“Weak bases may form buffer solution with reacting strong acid. If buffer solution forms there wont be any huge change in pH. So there will not be any proper colour change/visible difference while titrating. So excess hcl is added to make it acidic and then we neutralise it against NaOH so that we can get a visible difference. If we do direct titration there wont be any accurate titration point, any stable visible difference. That's why we need to do back titration.”

(Group -6, Trial -1)

“Weak bases can be titrated with strong acids thus acidic salt is formed. The salts are acidic in nature so to neutralise this we are adding a strong base that is NaOH.”

(Group-6, Trial-2)

Students have given theoretically reasonable arguments but they are not valid for this experiment.

Cluster-5

*“For this experiment we have antacids (weak base) and HCL is added in excess and then titrated with NaOH which is back titration. In some cases such as *in the case of CaCO₃ it is not dissolvable in water which does not give colour when indicator is added.* When HCL is added into the antacids we cannot say colour changes permanently or temporarily.”*

(Group-3, Trial-1)

“In experiment antacid weak base and HCL is added in excess and then titrated with NaOH because it's difficult to find exact end point, that is when there is exactly change of colour due to the indicator.”

(Group-8, Trial-1)

“Solubility is inversely proportional to pH. On using a strong base for titration, solubility decreases.”

(Group-1, Trial-2)

“Due to excess HCL present we cannot accurately determine the amount of HCL neutralised by antacid, thus we use NaOH to neutralise excess HCL.”

(Group-9, Trial- 2)

The responses in cluster-5 students have written incorrect answers, or even for correct answers, if the explanation is not correct (see the parts highlighted in green) it's categorized under Cluster-5.

There was another question in Post-lab (Appendix-D Q-12, Post lab). The question involved decision making between the use of direct or back titration for calculating the ANC for various types of antacids samples (hypothetical). In trial-1 all groups selected the correct method of titration and also gave the correct explanation. In trial-2 except for one group, all other 9 groups gave the correct answer. However, most of them have not written the explanation. It is possible that time constraint has affected the written explanation.

4.1.4 Observers' and Facilitator notes

The observers notes and researcher notes did present some comments which are related to students' conception of back titration. Observers were allowed to write their commentary; they were not specifically told to record the discussion for the back-titration question. Fortunately, in both trials, at least one observer recorded student discussion for back titration questions.

The following section presents such excerpts from the notes, these are their own reflections about the content that was being discussed during different stages of implementation. The quoted text indicates the content that was under classroom discussion by students at different stages for back titration discussion.

Trial-1

Observer 2:

“ The major responses (from the students) regarding Q. 4 (back-titration at stage-1) are

- In direct titration, an accurate end point can't be identified.*
- Weak base and Strong acid will form a buffer solution*
- Antacid solubility in water is low.”*

(Observer-2, Stage-1, Trial-1)

“ During the discussion of Q.7 (back-titration question at stage-2), instructors added some more discussions points such as

- Why letting the heated sample to come to room temperature*
- Why we are heating the solution*
- What is the role of temperature in this reaction”*

(Observer-2, Stage-3, Trial-1)

Similar observations were recorded by the facilitator (researcher) .

“One of the students who had performed the experiment earlier, initiated the discussion by giving reasons for back titration but he couldn't correlate the theory with the technical difficulties in the direct titration. Other students added points like buffer action and end-point detection. The discussion went for about 15 minutes or so. All the answers were considered, and students were told to reflect on this question during the lab experiment.”

(Facilitator-1, Stage-1, Trial-1)

“After the lab students were able to refine their explanations. In the post-lab activity, it was easier for students to observe the solubility and end-point but the slow rate of reaction needed to be facilitated by asking questions like why is heating required and why does the time change indicate the reaction.”

(Facilitator-1, Stage-3, Trial-1)

The above text by the observer and facilitator were based on classroom discussion that happened during pre-lab and post-lab. Thus, it presents the evidence regarding the aspects that were considered by students while answering the question prior to the experiment. These statements are also a part of students' written responses. This also indicates that at stage-3 (post-lab) students were struggling in understanding the rate of reaction as a possible factor for back-titration.

Trial-2

Observer 1:

“Q4 (back-titration question at pre-lab stage) took longer discussion, nearly 25 minutes. Facilitator was trying to help them arrive at relation to solubility. However, students weren't able to correlate it, could be due to lack of perceptible experiences.”

(Observer-1, Stage-1, Trial-2)

“After the lab session, they were able to comment on the question and need of back titration.”

(Observer-1, Stage-3, Trial-2)

Researcher (facilitator):

“Question related to back-titration was discussed with students, they were unable to come up with reasons. I tried to nudge them to understand the nature of antacid in water, but they were unable to link it with the titration process. A considerable amount of time was spent on this. Answers were not told to the students, students wrote their answers in the sheet based on their understanding.”

(Facilitator, Stage-1, Trial 2)

“After the post-lab activity, students were able to identify the reasons themselves. They could identify the slow rate of reaction through observation, but how it affected the titration process required a discussion.”

(Facilitator, Stage-3, Trial 2)

In Trial-2 at stage-1, students were unable to come up with the reasons for back-titration, it was challenging for them to think about the nature of analyte and its effect on titration. After the experiment and post-lab activity they were able to identify and explain the reasons with respective observations.

The observer and facilitator notes indicate that students were able to find out the reasons for back-titration in both the settings. As there is an agreement between observer's notes, students' written responses and facilitator's own observations, it indirectly presents as evidence about how students formulated their inferences in both the trials.

4.2 Response to other questions in the module

Students in trial-1 and trial-2 did not have prior engagement with inquiry-based labs as part of their chemistry lab courses. Thus, the presence of a facilitator was necessary for implementation of the module developed in the study. The facilitator tried to navigate the discussion in pre-lab and post-lab. Students, in pairs, discussed the answers to the questions before writing it in the worksheet.

In this section students' answers to different pre-lab and post-lab questions are commented upon in brief. It was observed that students in both the settings had similar types of inaccuracies with minor differences (choice of word, length of explanation) while answering the question in pre-lab and post-lab. Thus the analysis is not segregated between Trial-1 and Trial-2 but rather presented in the context of pre-lab and post-lab questions.

Pre-lab

Questions on how solubility is affected in addition to HCl, drawing indicator structure in deprotonated form, explanation of the sample with a higher ANC value have varied responses in terms of the explanation provided by students. For example, the parameters used to answer questions related to solubility range from use of Le-Chatelier's principle, solubility of the resultant salts, reaction b/w antacid and HCl and correlation between basicity and solubility of original sample solution.

While drawing the structure of deprotonated form of indicator, wrong representation of arrow pushing mechanism, incorrect valency of carbon, incorrect representation of formal charge on Oxygen atom in C=O and SO₃. Some of the groups did not change the representation related to C-O so as to depict the required change necessary for increase in conjugation.

The question related to the design of an activity to measure the antacid action received a variety of answers. This question was close to open ended and to best of my knowledge students do not engage with such types of questions in lab context. However it was observed all groups provided answers at least for one factor associated with antacid action. Some of them have explained two or three factors as well.

Some of the groups in both the trials gave all the necessary details for the activity whereas others did not give the procedural details of the activity for example, on pH change factor they wrote that the antacid which is able to increase the pH by a higher margin will be more effective, but they did not include details about how to measure that pH change for a given antacid sample. Some groups had only one experimental setup which included pH meter, antacid sample and HCl. Through this set-up they explained how they will measure the pH change, quick action as well as the relief time of an antacid with required variation in the procedure.

For both trials, 2 groups in total (Group-4 in Trial-1, Group-7 in Trial-2) discussed the method of direct titration to determine the quantity of hydrochloric acid that reacts with the antacid.

Responses to other questions in the pre-lab such as writing the reaction between antacid and HCl, determining the colour of the indicator from spectra etc were correctly answered by most of the groups .

Post-lab

In the post-lab, the answer to the question that asked to list all the chemical species present in the flask at different stages of titration had minor mistakes such as some of the groups missing silicates present in the tablet, the correct form of the indicator. They also wrote NaOH instead of NaCl.

It is interesting to note that two of the groups in Trial-2 mentioned the presence of SiO₂ after titration with NaOH. Based on the discussion in pre-lab on the different by-products of silicates reaction with HCl in different pH medium, they may have considered SiO₂ to be present at high pH.

While analysing the lab data the parameters related to ANC, were explained well by most of the group. Explanations provided by some of the groups for why the solubility is higher for suspension samples was either incorrect or ambiguous.

Co-relations between ANC and dosage were identified by all the groups in both trials. When asked about the differences in the action of tablet and suspension, all students mentioned relief time and quick action. However, some of the groups also considered the presence of laxative (sorbitol) in suspension and its effect on bowel movement.

The remaining questions in post-lab were related to calculations, determining dosage of antacid, change in titre value of NaOH were answered correctly by most of the groups.

The observer notes related to the overall module are quoted below.

“There was no discussion on Qn2 and everyone reached a consensus answer. Qn 3b had the maximum discussion and most of the students participated. The facilitator could have tried to elicit responses from all groups.”

“The design of the experiment is very good. Students also enjoyed solving the prelab and post lab exercises. As antacid is commonly used for acidity, they were able to connect to the experiment.”

(Observer-1, Trial-1)

“The questions in module generated good quality of discussion among students, The topic which initiated maximum discussion are: balance chemical equation for reaction of bases with HCl, pH change caused by antacid, relief time of antacids, solubility product calculation, protonated and deprotonated form.”

“The facilitator is asking authentic questions that invite groups a range of responses and elicit good- level thinking. The language of module is understandable and promotes students for co-constructing their own interpretations and response to questions.”

(Observer-2, Trial-2)

In order to have a better understanding of the trial and how beneficial it was for students in the learning process, it is important to look at the inquiry process through different lenses such as the responses by students, notes taken by the observers and facilitator. It is observed that not only do the responses that students write range from one group to another within the same trial, but they also differ from one trial to another. When it comes to the module, various students in different environments engage in their unique ways. Following this, the next chapter offers a thorough evaluation of students' perceptions regarding the inquiry lab.

Chapter 5- Analysis of Feedback responses

In the current study the second research question was to understand students' perceptions. A feedback questionnaire containing likert type questions and open ended questions was given after the implementation of the module (refer to Appendix-C). On an average a week was given to the student to submit their responses in both the trials.

All participants individually submitted their written responses. The feedback obtained from the three students (who did not participate in the post-lab session on Day-2) in Trial-2 was fairly incomplete and thus was not considered for analysis. Thus the feedback responses were obtained from 33 students (Trial 1- 16, Trial 2 - 17) . In the current chapter, these responses for both the trials are analysed to answer the research question 2.

5.1 Feedback on implementation and design of the module

This section primarily consisted of likert scale type questions 4 statements related to implementation and 5 statements related to design were given as a part of this question. The Figure-5.1 and Figure-5.2 indicate the distribution of responses obtained in both the trials for each of these statements. The statements are also indicated in these figures.

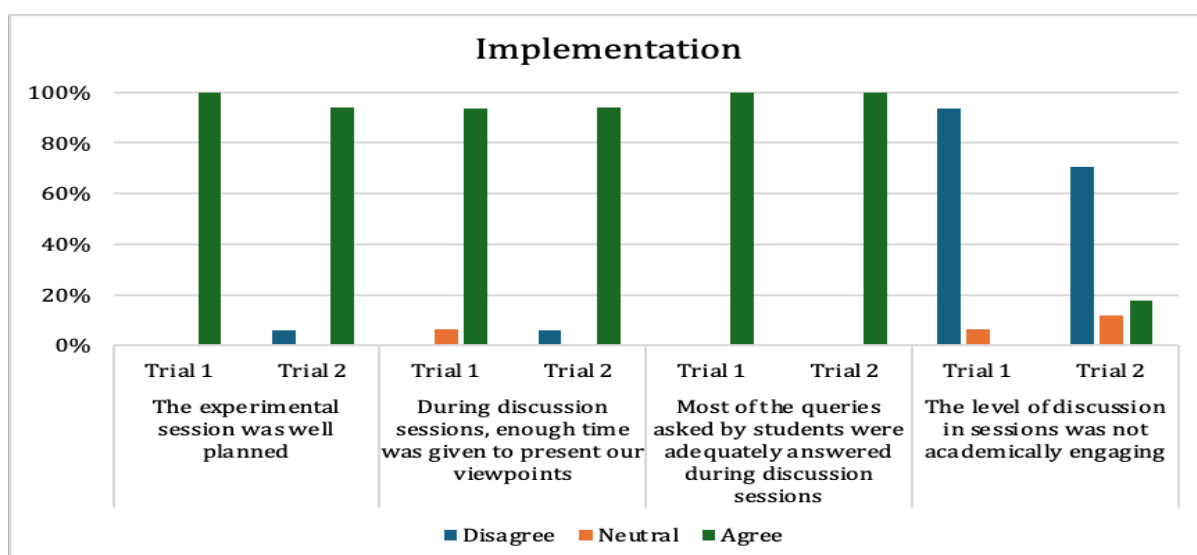


Figure 5.1 Students' feedback on the Implementation of module

Overall, students from both the trials had positive perceptions about the implementation of the module. The greatest variation is seen in the statement that says the discussion was not academically engaging in trial-2, with 71% disagreeing with it and 17% agreeing, the remaining section of the class is neutral to the statement.

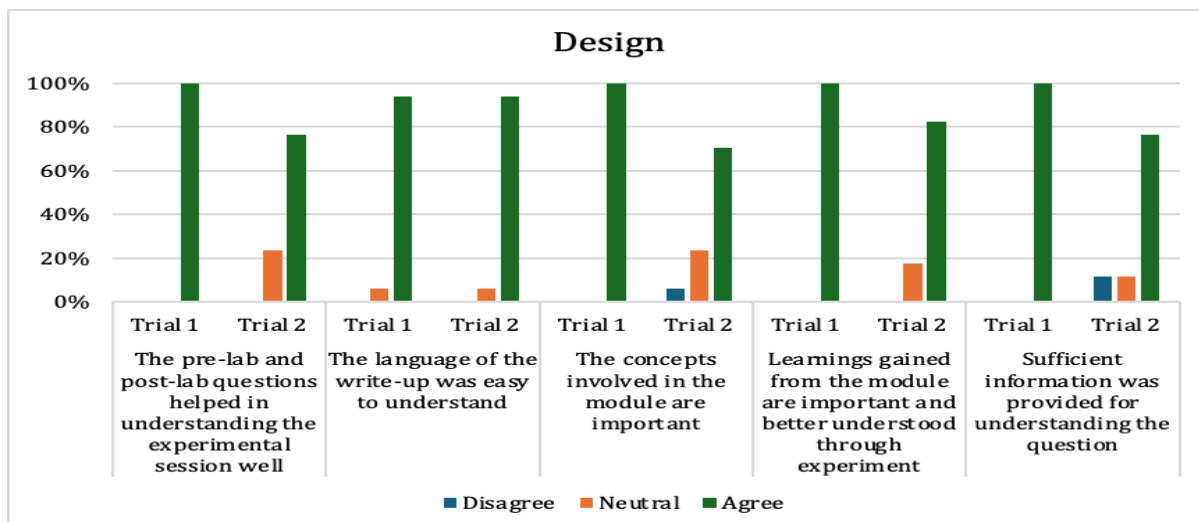


Figure 5.2 Students feedback on the design of module

For the design aspect of the module, students had overall positive responses on the pre-lab and post-lab questions, language of the module, concepts covered in the module, learning gains from the module, background information.

In Trial-2, over 80% of the responses for all the statements regarding the design of the module were largely positive, about 17% of the total response falls into the neutral category, and 3% of the total responses are in disagreement with the statements.

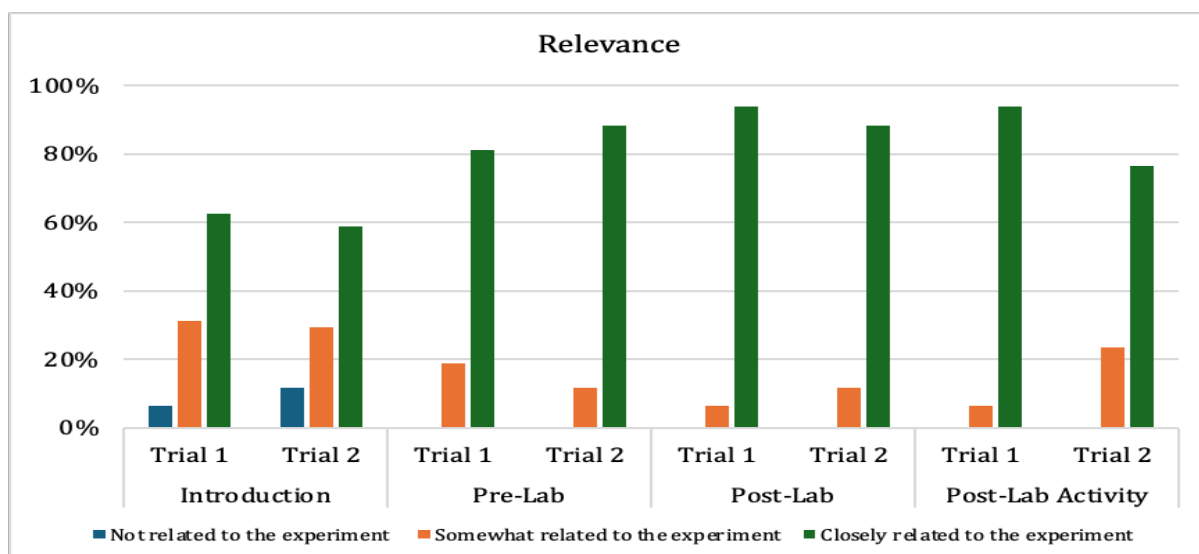


Figure 5.3 Students feedback on the relevance of subparts of the module

Regarding relevance of different sub-parts of the module and post-lab activity, out of the total responses for 3 subparts namely pre-lab, post-lab and post-lab activity, 90% of students from Trial-1 and 84% students in Trial-2 opined that were closely related to the experiment.

However, a relatively lower number of students felt that the introduction was closely related to the experiment. The figure 5.3 indicated the distribution of students' responses with respect to the relevance of different sub-parts and post-lab activity.

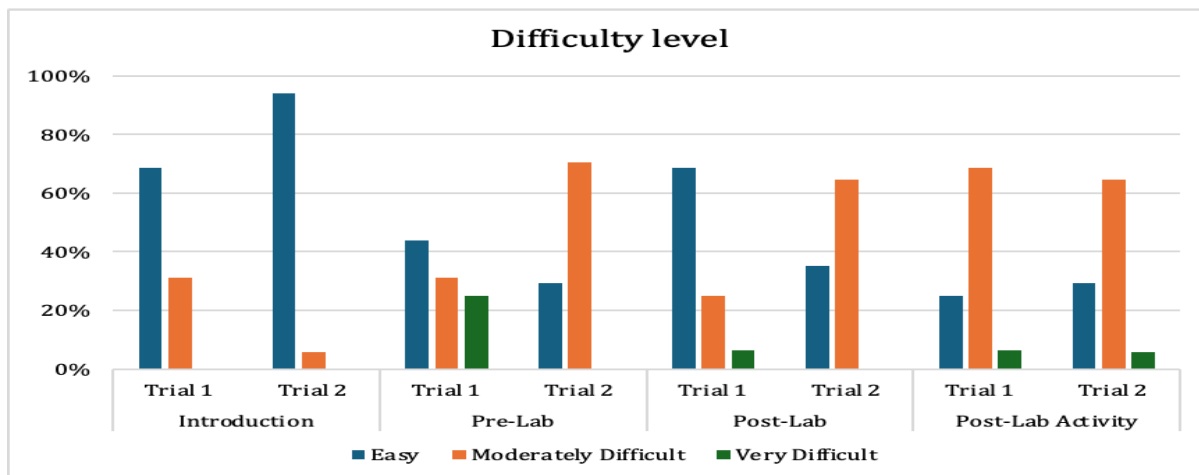


Figure 5.4 Students feedback on the difficulty level of subparts of the module

The feedback on difficulty level of different parts of the module and the post-lab activity, had varied responses in both the trials. 69% and 94% of students from Trial-1 and Trial-2 respectively rated the introduction on the easier side. The pre-lab questions were perceived as moderately difficult by 31% and 70 % in Trial-1 and Trial-2 respectively. However 25% of students in Trial-1 found the pre-lab to be very difficult. For Trial-1 68% and 25% of students perceived post-lab to be easy and moderately difficult respectively. However, a larger proportion of students 64% from Trial-2 perceived post-lab as moderately difficult. The post-lab activity was perceived primarily as moderately difficult by around 65% of the class in both the trials . The distribution can be seen in the below figure 5.4.

5.2 Analysis of the responses to open-ended questions

The following subsection presents analysis of responses obtained for open-ended questions. Overall, there were 9 descriptive questions that tried to capture the feedback from different aspects such as strengths of the module, challenges faced in the module, students' perception on the learning in laboratory, suggestions for further improvement.

The responses were analysed as explained in the earlier section 2.4.2, the categories and codes (from students responses and researcher's idea as abstracted from the students responses) along with their frequencies for different parts of the module are elaborated in this section.

5.2.1 Strength of the module

There were two questions related to the strength of the module, the first was about the best part of the module while the other was related to learning from the module.

The following table on the next page represents the categories observed after coding the responses on the best part of the module is in the below table.

Table 5.1 Analysis of the best part of the module

Categories	Preliminary Codes	Frequency	
		Trial-1	Trial-2
Structure and content of the module	Various subparts of the module, questions asked in the module, language of the module, concepts involved in the experiment	8	9
Learning specific concepts	Structure of indicator and its working, Back-titration, Chemistry of antacids.	4	0
Interaction with peers and facilitators	Pre-lab & Post-lab discussion	2	3
Doing lab experiment	Performing lab experiment	1	6

Representative examples from Students' feedback responses from both trials are given below.

Structure and content of the module

- *“The best part was that it was simple in language, was easy to understand and had concepts which helped us while performing the experiments.”*
- *“Questions asked in the module were relevant and gave us ideas how to question ourselves in different ways.”*
- *“I found the set of pre-lab leading into lab then post-lab the best part since it helps us engage with the problem in hand better.”*

Learning related to specific concepts

- *“Predicting resonance structure of Indicator-X which had increased conjugation in deprotonated form.”*
- *“Knowing the behind chemistry of antacids tablets and the experiment of titration related to it.”*

Interaction with peers and facilitators

- *“All the parts related with discussions, I really loved racking my brain; sometimes I felt really confused but it was an enlightening experience, I was able to clear a lot of concepts.”*
- *“Pre and post lab discussion.”*

Experimentation during lab task

- *“In the experiment the titration we perform was the best part and interesting to study.”*
- *“Performing the experiment and gaining the experience from it and learning in depth about back titration.”*

The following table 5.2 gives the distribution of responses under different categories as observed for the question two things that can be learnt by performing this experiment:

Table 5.2 Analysis of the learnings from the module

Categories	Preliminary Codes	Frequency	
		Trial-1	Trial-2
Chemistry of antacids	Parameters related to antacid action, ANC and its relation to dosage, relief time, comparison of tablet and suspension	11	12
Titration technique and associated concepts	Back-titration, application of titration, end-point related things.	8	11
Higher order thinking	Critical thinking, theory-practical linkage, designing a lab experiment	2	3

Verbatims:

Chemistry of antacids

- *“As a consumer, factors to consider before choosing an antacid; effectiveness of antacid (tablet and suspension).”*
- *“The most exciting part was learning how antacid samples are chemically analysed for ANC and other factors.”*
- *“How dosage of antacid is prescribed by doctor; the correlation b/w ANC, mass effectiveness and dosage.”*
- *“Tablet antacids are more effective in relieving acidity as per dosage neutralisation is more, though suspension antacids give faster relief.”*

Titration technique and associated concepts

- *“Understood two methods of titrations.”*
- *“Application in real life: it really helped me to understand how the titrations are linked to real activities (antacids).”*
- *“I learnt that colour changes of the reactant or mixture during titration doesn't always give the end point of the particular titration. Secondly I learnt that solubility affects the end-point of the observation table of experiment.”*

Higher order thinking

- *“If we can divide an experiment into separate parts then a lot of information can be found; understand very well.”*
- *“Way of thinking, of concepts and formulas which will be used in experiments. I learnt to co-relate and use the concepts during experiment.”*

5.2.2 Challenges faced by the participants

These questions seek responses regarding the most challenging part of the experiment and the difficulties faced with respect to different parts of the module including the post-lab activity. The responses for both these questions were clubbed together for the analysis.

The difficulties faced in different subsections of the module are listed below. Afterwards, these difficulties are further categorized into different types of challenges such as technical challenges, challenges with a concept or challenges associated with learning in general.

Table 5.3 Analysis of the challenges faced in the module

Categories	Sub-section of the module	Preliminary code	Frequency (for subsection)	
			Trial-1	Trial-2
Learning and conceptual difficulties	Pre-lab	Tough and confusing questions, thought-provoking nature of questions, difficult to focus for too long Questions related to indicator structure and solubility calculations	8	6
Technical difficulties	Lab	Technique of titration, end-point determination, doing titration, temperature of hotplate, weighing the samples	7	2
Conceptual difficulties	Post-lab	Calculation, Analysis of ANC, dosage, mass-effectiveness, difference in effectiveness of tablet and suspension	6	8
Learning and conceptual difficulties	Post-lab activity	Determining reasons of not doing a back titration through observations, understanding the variables involved, thorough knowledge and innovative thinking required	3	4
Learning difficulties	Overall module	Theory-practical connection, tricky question, difficulty in remembering concepts, solving some questions, time consuming, finding answers, understanding the rate of reaction as a reason for back titration	4	5
No difficulty		No difficulty faced, everything was well planned.	4	10

Verbatims

Pre-lab:

- *“Some pre-lab questions, I think before performing the experiment, it was tough to solve some pre-lab questions, there are some confusions while solving those questions.”*
- *“The most difficult part is first we can't write down the structure of the indicator but at last we were able to write down.”*

Lab

- *“According to me the challenges I faced in mastering the precise techniques required for performing the titration experiment, ensuring accurate results.”*
- *“The errors in measurement, and back titration was also challenging because it was my first time doing it.”*

Post-lab:

- *“Concepts of ANC, dosage and mass effectiveness.”*
- *“Understanding the difference b/w the effectiveness of suspension and tablet antacids.”*

Post-lab activity:

- *“Post-lab activity in that section discussion regarding the variables and fixed quantity are really difficult.”*
- *“Coming up with the answers for the post-lab activity, I wont call it challenging in a negative way. It was a different approach towards understanding a concept in detail.”*
- *“Post-lab activity required us to think in an innovative manner.”*

Overall module:

- *“Some questions seem to be quite tricky but it's kind of fun to solve them.”*
- *“For me, the challenging part was the way of executing the theories into the practical, how the theory is related to doing the experiment, how the chemistry is related, that's kind of confusing for me at first.”*
- *“When they asked to calculate solubility, I couldn't remember the formula so I could not understand how to do it.”*
- *“Even though the lab session was one of the interesting ones, it was a bit long.”*

No difficulties:

- *“Overall the module was well-planned and the language used was easy to interpret. So, there were not many challenges faced while going through the module.”*
- *“Nothing, everything was well explained and proper guidance was too available.”*
- *“None, all 3 sessions were easy to understand, pre-lab gave us the freedom to write our answers, post-lab was basic arithmetic and logic and the experiment was fairly easy.”*
- *“No, there wasn't any difficulty, the instructor guided through each step.”*

5.2.3 Student's perception of inquiry lab

There were two questions related to this aspect, one of the questions explicitly asked how the module has helped students to change their ideas about lab education. The other question was regarding the differences in learning (if any) by comparing this module with a regular lab setup. To make the analysis comprehensive both questions are analysed collaboratively.

There were three major themes that emerged for these responses, namely usability of the module, learners' understanding and positive impact on the affective domain of the students. Most of the responses interlinked all these three themes, so exact frequencies are not calculated.

Table 5.4 Analysis of Students' perception of the module

Categories	Preliminary codes
Usability of the module	A well-planned approach, a better way of doing experiments, real life application
Improved learners understanding	Conceptual clarity, understanding of procedural steps, interconnection between theory and procedure, real world application of concepts
Positive impact on affective domain	Thinking, asking question, exploring possibilities, finding answers, better retention, reasoning abilities, increased confidence

Verbatims: The verbatims are categorised according to the sentence's primary emphasis.

Usability of the module

- *“Yes, the experimental session was well planned, it included introduction, pre-lab, lab and post-lab sessions which helped me to understand theory and concepts easily. I wish this could be inculcated in my college.”*
- *“Yes, it gives a broad idea about doing experiments, what we are supposed to do before experiment and while doing the experiment in the lab and after (discussing the observation and analysing the data and finalizing the result) scientifically.”*
- *“Yes, this module was carefully planned and executed while experiments done by me were not organised as much. This is a more better way to perform lab experiments.”*

Improved learners understanding

Conceptual clarity:

- *“The current experiment module helped me to change my ideas about the lab experiment, I mean in my college the titration based experiments are taken very lightly, I never thought any titration related experiment can be discussed in such descriptive way.”*
- *“Definitely, the idea of building an experiment from a conceptual base and finishing with challenging the built concepts is refreshing.”*
- *“The discussions and questions for the pre-lab session and post-lab activity allowed for a more detailed understanding of concepts.”*
- *“Yes, I learnt 1000 times better through this experiment than through any other activity I had performed.”*

Procedural Understanding:

- *“Yes, it has made it possible to know why a particular step is done in an experiment and the concepts learnt in the theory.”*

- *“Since we were well equipped with the knowledge and know-how of the reaction during experiment, it was a bit easier to understand why the resulting phenomenon (colour change, pH change) occurs.”*
- *“Yes, here while performing the experiment, I was having a clear concept and idea that why am I doing this step or certain things in this way only, the clear concept was because of the pre-lab discussion which usually doesn't happen in regular lab sessions.”*

Real life application:

- *“It has highlighted real world applications of theoretical concepts. It bridged the gap between theory and practice, making lab experiments more meaningful and impactful.”*
- *“....more targeted exploration of real-world chemical processes, the module provides a specialized perspective on the chemistry of antacid compared to general experiments conducted in regular labs.”*

Positive impact on affective domain

- *“The module has opened horizons of lab experiments, asking questions is easier and confidence level in lab sessions has also increased.”*
- *“Yes, it increased my reasoning abilities and I got to know many things that were previously unheard of.”*
- *“Made us imagine(think) about possibilities that could have been. And further explaining as per our understanding.”*
- *“We have to find the answers on our own.”*
- *“Yes, it has changed my ideas to a lot extent. Prior to this kind of experiment I had not been exposed to such things and so thinking so deeply about an experiment did not happen earlier.”*
- *“We understand the process from all aspects properly here; at no point we thought that the teacher is dictating the process and we have to perform it accordingly.”*
- *“Yes, definitely here we had to understand each and every step properly and we were allowed to question every step.”*

Comparison to regular lab

There were no categories developed for these responses, broadly students compared the time differences, comprehensiveness of the module, solving questions, conceptual understanding, analysis of data, learning in lab as major differences with regular lab. The responses are quoted below.

- *“The regular labs were covered in 3 hrs, where we had our introduction, pre-lab and post-lab session altogether. It was too hard to gather and recollect all the information together but this module helped me (in) understanding of the experiments.”*
- *“Solving questions and understanding the experiment usually does not happen to such an extent that was done during this experiment of ours.”*
- *“Yes, it is little different in the experiment in the regular lab, in regular labs we mostly focus on the experiment part; in this experiment we are able to understand the experiment part and the topics or concept behind the experiment.”*
- *“In a regular lab, we did not try to analyse the data properly and did not try to do the direct titration thing for finding why it is not preferable.”*
- *“There were many learning. I learnt that how's an experiment actually done in the lab. There is no meaning of mixing two chemicals and saying it as lab experiment. Knowing and analysing, applying different concepts, exactly understanding the purpose of that experiment is the the main point which I learnt here.”*

5.2.4 Suggestions for further improvement

Questions about the unclear part, irrelevant part and suggestions from students were analysed in this category. For the analysis only the responses that can serve as a basis of improvement are analysed. The positive or neutral statements are not discussed here.

For the irrelevant part of the experiment, 3 students (out of 16) opined that a few repetitive questions can be deleted in trial-1. For Trial-2, 3 students (out of 14, 3 students left it blank) responded that a few pre-lab questions, post-lab activity and certain repetitive questions in the module can be deleted respectively.

In Trial-1, regarding the unclear part of the module, 8 students (out of 16) mentioned different things, this included questions related to solubility, choosing an indicator for post-lab activity, how parameters related to ANC differ for tablet and suspension. During the lab work, end-point determination, exact temperature of hotplate were other things mentioned by the students. In Trial-2, all students felt that no part of the module was unclear to them.

Students did not give meaningful suggestions when they were asked to respond to the question related to other suggestions. Perhaps, this question was not clear or not reflected upon by the students.

5.3 External Individual response to the students feedback

As explained in section 2.5, two external individuals also analysed students' feedback responses. The detailed answers of the external individuals for each question in both the trials are given in the Appendix-E.

Individual-1

The design of the module is appreciated by the students. Interaction with instructors and group members, simplicity of language used in the module played a central role in the process of understanding the module. Some students felt difficulties in some of the pre-lab and post lab questions. And they found it repetitive. And some of the feedback responses indicate that students are expecting clarity regarding the end point detection (Color).

(Trial-1)

Students seem more welcoming to discussion based laboratory sessions that include real life applications. It was found that students do not feel that they are unclear about any topics even though they face difficulty in understanding some concepts; this has to do with the fact that the instructors helped them to clarify their doubts.

(Trial-2)

Individual-2

The students are satisfied with the language and clarity of the module. They like that they were given the opportunity to speak, discuss and express themselves. This sense of being active in their own learning helped them reach better conceptual clarity.

(Trial-1)

Overall, it echoes throughout the responses that the students were comfortable with the approach and felt more comfortable to voice their questions and answers. However, it also shows that not every student perceives it to be the same. For example- for one student a post-lab question seemed to be basic and for another it was challenging. Another student also expressed their concern about the total time spent on the experiment.

(Trial-2)

Differences between Trial 1 and Trial 2

External individuals were also asked to reflect on how the feedback is different in both the settings, their answers are written below.

Individual 1 - Trial 1 responses majorly revolves around the pre-lab and post -lab discussions or we can say it was about the concept related part whereas trial -2 responses revolved around the experimental part. In trial 1 responses, students commented about the peer discussion but it was not in trial -2.

Individual 2 - In trial 1, in a few instances students have reported some parts of the module that were not clear to them. In trial 2, all responses show that no part was unclear to them. Otherwise student's responses in terms of their understanding and the challenges they face, are largely similar in both trials.

There is a considerable overlap between the researcher's and individuals' analysis, the responses of individuals align well with the categories described by the researcher. The difference in frequency for each trial by researcher is also noticed by individuals as major differences in both the settings. Overall, the researcher agrees to the comments made by both the observers for both settings.

5.4 Discussion

This section focuses on some of the significant patterns identified in students' feedback responses. In the discussion, both the analysis of the researcher and the analysis of the external individuals are used.

A good proportion of students in both settings were largely positive about the design and implementation of the module. Overall, in both settings, the module's language was relatively easy for the majority of students.

For Trial-1 the distribution of responses about the difficulty level of the pre-lab is varied. Specifically, 44% students found it to be easy, 31% students found it to be moderately tough, and the remaining 25% students found it to be very difficult. The disparity in academic backgrounds of the students, stemming from their diverse backgrounds in various colleges around the country, may account for the varying levels of difficulty experienced by different individuals. In Trial 2, this was not the situation, as all participants come from the same geographical region as compared to students participants from Trial-1. Perhaps with experience the facilitation process by the researcher has probably become better as compared to that in Trial-1.

One of the striking observations is that in both settings students have reported similar learning outcomes. In their opinion the first learning outcome is related to back-titration and the second is chemistry concepts associated with ANC.

Prior to trial 1, the researcher was inexperienced regarding the possible errors that can happen at students' end during the titration. Trial-1 sensitised the researcher about the same who made the compilation of errors from the students' answers, her own observations (the facilitator's records) and external observers. For Trial 2, required minor modifications in the procedure description were added and students were presented with demonstration of performing the titration technique appropriately. Such efforts helped in minimising the technical challenges faced by students in trial-2.

The students were experiencing an inquiry-based lab for the first time, and they supported the advantages of this approach and how it improved their learning. In Trial-1, all responses indicated that students were open to inquiry-based instruction. In Trial-2, all but one of the 17 responses received were positive with respect to inquiry approach. In both settings, students appreciated the pre-lab, lab, and post-lab approach. They stated this approach was useful in enhancing their knowledge of procedures and concepts related to the experiment. The pre and post lab discussion assisted in the same. They also mentioned the interconnection of experiment to everyday context was useful in engaging them in the module. Overall, students felt that such module(s) can be part of their regular lab course.

Even though certain difficulties were mentioned by students as explained in 5.2.2, they did not feel overwhelmed by these difficulties. The subparts which were identified as difficult by the students were not seen as irrelevant and they did not disregard the same. Students were mindful of the fact that despite the challenges posed by particular sections, they are important.

Chapter 6- Conclusion

The objective of the study was to create an inquiry-based module that is suitable for an undergraduate chemistry laboratory. The primary aim of choosing antacid (determined via back-titration) as the subject for developing this module was to design a module that has low technical requirements, applies to daily life, includes chemistry concepts from the undergraduate chemistry curriculum, and facilitates meaningful integration of inquiry. These criteria enable the designed module to be implemented in the undergraduate laboratory of any college with adequate laboratory resources. The developed module rigorously standardised the experimental technique in the laboratory for various types of antacid samples, their quantities, and safety considerations. The first draft is validated by experienced experts who possess extensive knowledge of the inquiry approach. It is then implemented to a group of teachers coming from various geographical regions within the state of Maharashtra. The feedback that was received from experts and teachers resulted in the standardisation of the module in terms of language, clarity, order of the questions, especially the sequence of the direct titration activity. The modified version was subsequently implemented with two distinct groups of students in two different settings. The first study took place at the institute where the researcher was located, whereas the second trial happened in the students' natural setting.

6.1 Insights to the Research Questions

The study focused on two primary research questions. This section explains the answers to these questions, which are derived from the analysis done in the previous chapters of the thesis.

1. What do students' responses indicate about their comprehension of the back-titration method acquired through the inquiry-based module?

The data analysis presented in chapter 4 of the thesis, indicates that at stage-3 (Theoretical discussion & Back-titration and Direct titration observations) students' responses shifted from (initially before the experiment) Cluster-4 and 5 to Cluster-1 and 2. It means that at stage-3 students were able to deduce the correct explanations from the observations and data obtained in both direct-titration and back-titration.

The majority of the groups were also able to establish a connection between what they saw and the reasons behind them. For this shift to happen, students must utilise the learning opportunities provided by the inquiry-based module. As explained in section 1.2 the module provides opportunities for careful observations, data collection, drawing reasonable conclusions based on their observations and data and all this facilitated students to find the reasons for using the back-titration method for calculating ANC values of different antacid samples. Students were also navigated through this inquiry through relevant cueing questions and background information relevant to the experiment.

Hence; it can be concluded that the module has helped students in changing their understanding related to back-titration and since the clusters are hierarchical, the shift is in a positive direction. To confirm the accuracy of their understanding, participants were tasked with selecting the appropriate titration method for unfamiliar situations. The responses to this additional question to choose between direct or back titration for unknown samples of antacids further

demonstrated their comprehension of back-titrations as they could apply their reasoning to make a right decision in new situations as well.

All this indicates that the expected investigation for the designed Level-1 inquiry module has taken place, as students were able to formulate their analysis and provide explanations for the collected data and observations.

2. How do undergraduate students perceive inquiry-based instruction in the laboratory setting?

Chapter 5 of the thesis offers a nuanced examination of student perceptions within the two distinct laboratory settings. While these settings possessed unique characteristics, the overall experience was positive. Students appreciated the strengths of the module and the breadth of learning opportunities it provided.

Although students identified a few challenging aspects of the module they did not feel intimidated by them. The students did not consider the subparts that they identified as challenging irrelevant, nor did they neglect them. Students were aware that certain parts are important even though they can be difficult at times.

Students valued the pre-lab, lab, and post-lab approach in both settings. They indicated that this method helped them better understand the concepts and methods involved in the experiment. Pre-laboratory and post-laboratory discussions helped with this as well. Perhaps the approach presented clarity about the task at hand. Furthermore, students reported increased involvement, suggesting that the module allowed active participation. There were comments related to deeper reflections on the learning from the lab indicating that students abstracted the way of learning that is useful in laboratory settings. They also said connecting an experiment to everyday life helped them engage with the material. Overall students felt that such modules can be a part of their lab courses.

6.2 Limitations

The developed inquiry module was tested in two different settings of which one trial was in students' own college lab. It is important that the developed module is further tested in various diverse authentic settings so as to standardise it. Such a data collection will help in comprehending the challenges associated with implementation of such lab modules, hence enhancing the understanding of the factors to be considered while developing such instructional material for chemistry lab courses. For Trial-1, although students were from different parts of the country, the trial was conducted in the institute with excellent infrastructure facilities and thus it was only able to provide a partial understanding of the challenges.

In both trials, the researcher took the role of facilitator, even though for the first trial, another experienced person was also facilitator along with the researcher. Researcher's own exposure to the process of facilitation was limited and needed more exposure to various diverse settings. It is important that such trials are also conducted by another facilitator (apart from researcher) so as to avoid biases if any. As a researcher, I realised that the process of facilitation is central for implementation of inquiry based modules and thus teachers need to undergo such experiences before implementing the inquiry based approaches in their classroom.

The researcher's own exposure and training in educational research, especially qualitative research methodology, was limited. The work involved development of the module, its standardisation in the lab, its iteration through feedback from teachers and experts and data analysis primarily using qualitative methodology to gain valuable insights about the development and implementation aspect. However, only written reports were collected. No interviews, audio recordings, or video recordings were conducted. In the time frame of the project, it was rather difficult to follow/adopt all the nuances of qualitative research methodology, even though efforts were made to bring different experts to validate the process from time to time. Thus I acknowledge the study can be refined further.

6.3 Future Directions

I am keen to implement the developed module in different authentic settings provided they are accessible to me and mature myself as a facilitator. The module can be tried out by an experienced teacher who has experience in facilitating in their classroom where I (along with others) would like to be an observer. Such a trial will help in understanding the extent to which this module helps in affecting students' comprehension of back titration.

Additionally, I am keen on developing a Level-1 inquiry experiment related to antacid samples but in different domains such as complexometric titration. Both these modules can be implemented together as back-titration is the central idea for the estimation through acid-base or complexometric titrations. Students will also get the opportunity to compare both these approaches for estimation of antacid samples.

Another possibility is to develop the same module with inquiry level-2 however implementation of such module needs to be done carefully especially for students who come only with expository background. It is possible to study the challenges involved with such an inquiry level and are students able to transit themselves to higher levels of inquiry. Higher levels of inquiry modules will certainly require presence of scaffolds when the open inquiry approach is used.

Appendices

Appendix-A Consent Form

The following acid/base titration experiment has been designed as a part of my Master's project in the area of chemistry lab education. The project is being done under the guidance of Prof. Savita Ladage from HBCSE-TIFR. The experiment is designed in an Inquiry-based approach as a part of R & D work in the field of chemistry education. Whenever such a development is done, it is important to get critical feedback from well-experienced faculty members and students involved with the chemistry laboratory courses at the UG level. We (me and my mentor) thus request you to give your critical feedback about the module. Please give your honest responses and they will help us to standardise the module further. Your feedback and written responses on the module may be used for chemistry education research purposes only. Your identity will be kept confidential if your written responses are used for CER purposes. The obtained responses will not be kept in the public domain and are accessible only to us as researchers. If you have any questions regarding data handling and confidentiality, please feel free to contact us at jashika@students.iiserpune.ac.in , savitaladage@gmail.com. We thank you for your time and valuable support.

Jashika
(BS-MS student, IISER, Pune)

Savita Ladage
(HBCSE, TIFR)

To be filled by the students (this is an anonymous form)
I have read the above information carefully. I give my consent to use my written responses in and during discussions for chemistry education research purposes only.

Signature:
Date:

Appendix-B Feedback form for experts and teachers

A. Please tick in the appropriate column as applicable to you.

The concepts involved in the module	Not important	Somewhat important	Important
Overlap with the UG curriculum	To a lesser extent	To some extent	To a considerable extent
Background information provided	Not Sufficient	Sufficient but not in totality	Sufficient and in totality.
Language of the module	Easy to understand	Moderately difficult to understand	Very challenging to understand
Length of the module	Very short	Moderate	Very long
Difficulty level of the module	Easy	Moderately difficult	Challenging
Learnings gained from the module	Important but can be better understood theoretically	Important and better understood through experiment	Important and can only be understood by experiment.

B. Tick in the column which you find the most appropriate.

	Not related to the experiment	Somewhat related to the experiment	Closely related to the experiment
Introduction			
Pre-lab			
Pre-lab activity			
Post-lab			

	Easy	Moderately difficult	Challenging
Introduction			
Pre-lab			
Pre-lab activity			
Post-lab			

Open ended question:

Common questions for both teachers and experts

The best part of the module

The most challenging part of the module

Irrelevant part of the module which can be deleted

Two things that can be learnt by performing this experiment

Differences (in terms of learning) as compared to regular labs

The difficulties and challenges that can be faced by students while performing the experiments

Any other suggestions w.r.t. module

Extra question for expert- Two Changes that you would like to suggest if you would have designed the experiment

Additional questions for teachers

Whether the current experimental module has helped you to change your ideas about the lab experiment? Explain your answer in brief

Any part of the module which was not clear to you

What were the difficulties and challenges faced while going through the module or while performing the experiment in the lab

Do you think this module can be implemented in UG colleges like your own colleges? Explain in brief.

Appendix-C Feedback Form for students

Category-1: Implementation and design of the module

		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Implementation and Facilitation	The experimental session was well planned					
	During discussion sessions, enough time was given to present our viewpoints					
	Most of the queries asked by students were adequately answered during discussion sessions					
	The level of discussion in sessions was not academically engaging					
Design of the module	The pre-lab and post-lab questions helped in understanding the experimental session well					
	The language of the write-up was easy to understand					
	The concepts involved in the module are important					
	Learnings gained from the module are important and better understood through experiment					
	Sufficient information was provided for understanding the question					

	Not related to the experiment	Somewhat related to the experiment	Closely related to the experiment
Introduction			
Pre-lab			
Post-lab			
Post-lab activity			

	Easy	Moderately difficult	Very difficult (Challenging)
Introduction			
Pre-lab			
Post-lab			
Post-lab activity			

Category-2 Strength of the experimental module:

1. The best part of the module
2. Two things that can be learnt by performing this experiment

Category-3 Challenges faced in the module

1. The most challenging part of the module
2. What were the difficulties and challenges you faced while going through the module or while experimenting in the lab?

Category-4 Student's perception about learning from a lab:

1. Has the current experimental module helped you change your ideas about the lab experiments? Explain your answer in brief.
2. Any Differences (in learning) as compared to experiments in regular labs.

Category-5 Suggestions from students.

1. Any part of the module which was not clear to you
2. Irrelevant parts of the module that can be deleted
3. Any other suggestions w.r.t. module

Appendix-D List of titration experiments

Titration experiment:	Offered in which year	Content of the experiment
Acid-Base titration experiment through pH meter	1st year- CH1223, January 2023	Chemical and apparatus required, standardization of solutions, estimating strength of unknown acid, advantages of pH meter, steps for data analysis is given
Iodometry titration: Estimation of Iodine in iodized common salt	1st year- CH1223, January 2023	Chemical and apparatus required, procedure, analysis-formula and reactions given.
Complexometric titration: Estimating Calcium in milk powder	1st year- CH1223, January 2023	Theory, chemical and apparatus, procedure, no formula given, Data analysis is mentioned in detail
Back-titration: Determination of Acid-Neutralizing power of Commercial Antacids	2nd year- CH2243, August 2023	Theory, chemical and apparatus, procedure, formula given, no post-lab question
Conductometric titration- Acid-base Titrations using Conductivity Method	2nd year- CH2243, August 2023	--
Redox titration- Determination of Iron by reaction with permanganate	3rd year- CH3253, January 2023	Introduction with theory, all the chemical reactions and concepts, chemical and glassware required, Procedure, Reporting Result, 3 post-lab conceptual questions- (no direct formula given)
Precipitation Titration Determination of Chloride by Mohr's method	3rd year- CH3253, January 2023	Introduction with theory, all the chemical reactions and concepts, chemical and glassware required, Procedure, Reporting Result, 3 post-lab conceptual questions

Appendix-E Designed Module

Introduction:

The word antacid perhaps is familiar to us. Most of us will connect it with medicines consumed when we feel uncomfortable after consumption of heavy oily food or when we do not take food for a long time. We probably say that the acidity has increased and I need to take an antacid. Let us try to figure out what we mean by words like acidity. We know that the stomach secretes hydrochloric acid, which helps in digesting food. However, sometimes when excess acid is produced as compared to normal levels in the stomach, it rises from the stomach and reaches the food pipe or throat. We then start feeling uneasy and feel a sour taste in the mouth.

To comfort ourselves, we usually take some tablets or oral suspensions. The purpose of such medicines is to neutralise the increased amount of secreted hydrochloric acid and hence, lower the acidity. All such medicines are called “antacids”- that act against (anti to) the acid. There are many different antacid products in the market which are available usually in different forms like powder, chewable tablets and oral suspension/liquid. They contain various kinds and amounts of active antacid ingredients and other ingredients like binders, flavourings, fillers etc.

Some of the common antacids and their compositions:

Mention a few antacids that you have heard of or used in the past.

The table below describes four antacid samples. It will refresh your memory about the composition and amount of ingredients present in various samples. Additionally, it will help you to answer the questions related to antacids below.

	Sample 1 (per tablet)	Sample 2 (per 5 ml)	Sample 3 (per tablet)	Sample 4 (per tablet)
Magnesium Hydroxide	250 mg	250 mg	25 mg	-
Aluminium Hydroxide	250 mg	250 mg	300 mg	-
Calcium Carbonate	-	-	-	1000 mg
Magnesium Aluminium Silicate Hydrate $MgAl_2(SiO_4)_2 \cdot nH_2O$	50 mg	-	50 mg	-
Dimethicone (D)/ Simethicone (S)	50 mg (D)	50 mg (D)	25 mg (S)	-
Sorbitol Solution	-	1.25 g 70% (w/v)	-	-
Recommended dosage	1 -2 tablets	5-10 ml	2-4 tablets	1-2 tablets

Composition of antacids:

Active ingredients of antacids are weak bases like hydroxide, trisilicate, carbonate and bicarbonate of various metals like aluminium, magnesium, and calcium generally, which neutralize the acid.

There are a few non-antacid active ingredients like dimethicone (a polymer with molecular formula $CH_3[Si(CH_3)_2O]_n Si(CH_3)_3$) and simethicone (made by mixing dimethicone with silicon dioxide) that work as anti-flatulent and anti-bloating agents. They decrease the surface tension of gas bubbles, allowing them to come together and releasing the gas through flatus (farts) or belching (burping). Sorbitol, a sugar alcohol with molecular formula $C_6H_{14}O_6$ acts as a laxative by drawing water into the large intestine. Thus, it stimulates bowel

movements and helps in relieving occasional constipation too. [1,2] Inactive ingredients such as colouring and flavouring agents etc. are also used.

Q 1. From the above table, write the chemical formula for all the active (weak bases only) ingredients. Also, write the balanced chemical equation(s) for their reaction(s) with HCl (similar reactions take place in the stomach when you consume antacids).

Q 2. Given below are pairs of antacid samples, predict which one among each pair will be more effective, and explain your answer.

a) Sample A: 400 mg of $\text{Al}(\text{OH})_3$, Sample B: 400 mg of $\text{Mg}(\text{OH})_2$

b) Sample C: 400 mg of $\text{Al}(\text{OH})_3$, Sample D: 600 mg of $\text{Al}(\text{OH})_3$.

Q.3 For studying and comparing various types of antacids, it is important that we decide on some measurable criteria. We can use a chemical analysis to get a numerical value that is related to the action of the antacid. In this way, their actions can be compared and studied systematically. You can design your criteria by using the following factors:

- i) The pH change caused by the antacid in the stomach
- ii) Amount of the acid reacting with the antacid in the stomach
- iii) Quick action
- iv) Longer relief time
- v) Solubility and absorption in the stomach
- vi) Negligible side effects

a) Which of the above factors can be measured through chemical analysis known to you? Mention the corresponding number in the box below.

b) Choose one or more from the given factors and explain how you can measure them chemically.

Elaborate on how it will help to compare different types of antacids.

c) If you were to select an antacid for yourself, which of the above factors would be most important to you? You can choose based on your personal preferences and experiences. Put a tick against that factor in the above list.

Acid/Base titration experiment:

Our task:

In the current laboratory task, we will investigate antacid samples and associated chemistry. When such medicines are prescribed by the doctors, they prescribe the fixed doses of such medicines. Perhaps by the end of the task, we will get a feel for the prescribed dosage.

Please note:

- The experimental module has three parts, pre-lab, lab and post-lab.
- The pre-lab questions will help in revising some of the important concepts related to the experiment. Answering or pondering over these questions will prepare you to perform the lab work with understanding.
- During lab work, the focus should only be on performing the task. You will enjoy carrying out the lab work.
- After the lab work, post-lab questions will help to reflect on the data collected, and challenges faced (if any) and we will understand the chemistry of antacid drugs.

Brief Description of the experiment:

In this experiment, we will find out the acid neutralising capacity (ANC) of two antacid samples (Sample-1 and Sample-2 from the table on page 1). Here, ANC is defined as the amount (specifically millimoles/moles) of hydrochloric acid that the antacid sample can neutralize.

When a weighed sample of an antacid is dissolved in a measured excess of HCl solution, the antacid can neutralise some of the acid. The remaining unreacted acid in the flask can then be titrated with a standard

NaOH solution using a suitable indicator. The difference between the total moles of HCl added to the antacid and moles of HCl neutralised by NaOH will give the ANC value for the chosen sample.

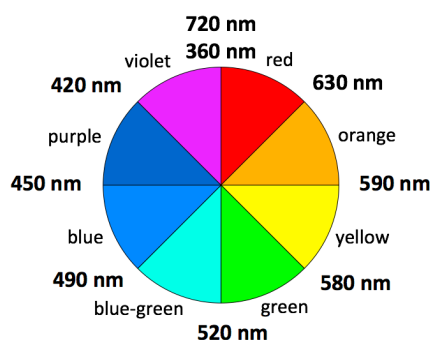
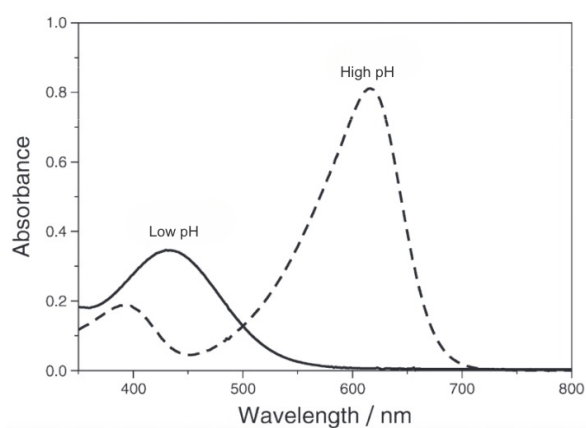
Pre Lab questions:

Q 4. The solubility of antacids is an important parameter. It decides how much antacid is available to react with HCl in the stomach. The solubility product (K_{sp}) for the active ingredients is mentioned below. K_{sp} for $Mg(OH)_2$ is 7.1×10^{-12} and $Al(OH)_3$ is 3.0×10^{-34} at 298 K.

- Calculate the solubility (in moles/L) of the active ingredient separately present in the given sample. Also, mention whether the sample solution of $Al(OH)_3$ and $Mg(OH)_2$ will be soluble or insoluble corresponding to the solubility value.
- When aq. HCl solution is added to the antacid sample, how do you think the solubility will change? Explain.

Q 5. In any acid-base titration, an appropriate choice of indicator is important to detect the endpoint visibly. An indicator is usually an organic dye that behaves as a weak acid or a weak base and gives a visual indication of the system's pH. Different indicators undergo protonation and deprotonation at different pH, and we choose the one best suited for any given titration. In this experiment, we are using 'X' as an indicator.

- Given below is the visible absorbance spectra of indicator 'X' at a low pH (-solid line) and at a high pH (-dashed line) [3]. The corresponding absorbed wavelengths are 453 nm and 616 nm respectively.



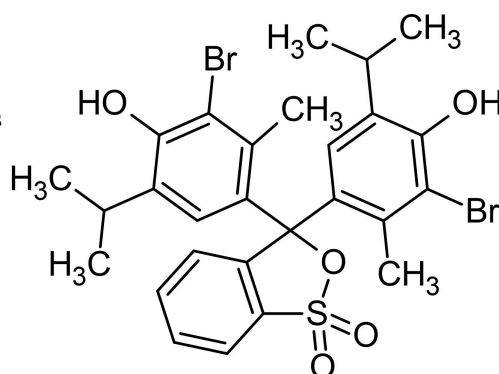
- What will be the colour of the protonated and deprotonated form? You can use the colour wheel to determine the colour of the indicator solution. The colour that is opposite to the absorbed wavelength is the observed colour of the solution.
- In the graph you can see the change in maximum wavelength from low pH to high pH. This shift towards a higher wavelength is known as a redshift or bathochromic shift. There can be many reasons for the shift as given below. What reason do you think is most appropriate in the case of X when going from low pH to high pH:

- Increase in conjugation
- Substitution with a group containing lone pair or non-bonding electron
- Increase in solvent polarity

Explanation

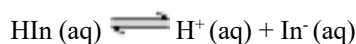
b) The structure of "X" in a fully protonated state is shown:

- Identify and circle all the protons that can be exchanged in a basic medium in the given structure.



ii) Draw the possible structure(s) of X in deprotonated form, considering only one of the Hydrogen atoms are deprotonated.

c) Given below is the general equation of indicator equilibrium:






For 'X' the pK_a value is 7.2, based on it answer the following questions:

- What will the solution's pH be when the concentration of HIn is equal to In^- ?
- In indicators with two different colours, generally, only one colour is seen if the ratio of the concentration of the two forms is 10:1. It means at acidic pH the concentration of HIn is 10 times that of In^- , giving a specific colour. At basic pH, the concentration of In^- is 10 times of HIn, giving another specific colour. The colour transition happens between these two concentration ranges of HIn and In^- . From this information, determine the pH range of the indicator X, in which it can be used.
- Go through the description for the experiment (on page no. 4) and write the colour change at the endpoint for this titration.

Q 6. Which of the two samples, sample-1 and sample-2 (from the table on page 1) will have a higher ANC value and why?

Q 7. In theory weak bases can be titrated with strong acids. But for this experiment, we have antacids (weak bases) and HCl is added in excess and then titrated with NaOH. What could be the possible rationale for doing that?

Chemical required	GHS	Placed in
0. XXX HCl		Reagent bottle
0. XXX NaOH		Reagent bottle
Bromothymol Blue (BTB)		Dropper bottle
Antacid sample	—	To be weighed

Glassware required	Qty.
Burette (25 mL)	2
Conical flask (100 mL)	3
Funnel	2
Measuring cylinder (25 mL)	1
Hot plate	1

It is helpful if you are familiar with the chemical hazard symbols. Such awareness gives a better understanding regarding handling and disposal of the chemicals you are using.



Harmful Irritant



Corrosive

Safety precautions:

- Use a lab coat, safety goggles, shoes and gloves while handling the chemicals.

Note:

- The indicator solutions are kept in common.
- Exact molarity of NaOH will be provided at the time of the experiment.

Procedure:

Blank titration of HCl:

1. Fill the given aqueous solution of NaOH and HCl in two separate burettes and label them.
2. In a conical flask take 15 mL of water and add 12 mL of HCl solution from the burette. Add 2-3 drops of BTB indicator to it.
3. Titrate the solution with NaOH until colour changes at the endpoint. Enter the reading in the data table given below. and then repeat another titration.

If the two readings vary by more than 0.2 mL, then a third reading should be taken.

Note: The colour change is from yellow to blue but you may observe a green colour (intermediate colour near the endpoint) if you do the titration slowly and carefully. Both the endpoint colours are fine and differ only slightly by a few drops.

	Trial 1	Trial 2	Trial 3
Initial burette reading (mL)			
Final burette reading (mL)			
Volume of titrant (mL)			

Note for Antacid's Titration:

1. Please go through the observation table on the next page. Fill in the information about the solubility of the sample solution (insoluble, soluble, suspended particles, clear solution, etc.) and the observed colour. **After finishing each step of the procedure, you have to write the observation.**
2. The colour change is from yellow to blue, there can be some colour interference as the sample solution is coloured but it will not affect the end-point detection.
3. In addition, please take a photograph of the solution in the mentioned steps, which can be used later for observational purposes.

Sample Preparation:

Tablet: Take the given antacid sample and weigh it in a balance that has the least count of 0.001 g. Then grind it with a clean and dried mortar and pestle to make a fine powder. Tare the weighing paper on the weighing balance, weigh 0.200 g of the tablet and transfer it into a 100 mL conical flask and store the rest in a vial. Note the exact weight of the sample in the lab sheet.

Suspension: The sample will be provided in a beaker to you. Tare a conical flask on weighing balance, and with the help of a dropper transfer around 0.85 g of the sample to the conical flask. There can be little variation in the weight but try to keep it in the range of 0.85 to 1.00 g and write the weight in the lab sheet.

Titration (Same for both samples):

1. Add 15 mL of distilled water to the flask containing the antacid sample, swirl the mixture to dissolve it and add 5 drops of BTB indicator. Pre-heat the hot-plate at around 150°C.
2. Add 12 mL of HCl accurately from the burette to the sample solution.
3. Gently boil the mixture on a hot plate for 15 minutes till it becomes clear, then allow the solutions to cool down to room temperature (to touch).
4. Titrate the solution with NaOH solution until the indicator colour change happens. Enter the reading in the data table below, and then repeat another titration with the remaining samples.

If the two readings vary by more than 0.3 mL (there could be slight variation in the mass of the liquid sample which can affect titre volume), then a third reading should be taken.

Observation table:

	Sample 1 (Tablet)		Sample 2 (Suspension)	
	Solubility	Colour	Solubility	Colour
Step 1				
Step 2				
Step 3				
Step 4				

Antacid titration:

Sample-1 (Tablet)

	Trial 1 (mass:)	Trial 2 (mass:)	Trial 3(mass:)
Initial burette reading (mL)			
Final burette reading (mL)			
Volume of Titrant (mL)			

Sample 2 (Suspension)

	Trial 1 (mass:)	Trial 2 (mass:)	Trial 3(mass:)
Initial burette reading (mL)			
Final burette reading (mL)			
Volume of Titrant (mL)			

Post-lab question:

	Sample 1 (per tablet)	Sample 2 (per 5 ml)
Mg(OH) ₂	250 mg	250 mg
Al(OH) ₃	250 mg	250 mg
MgAl ₂ (SiO ₄) ₂	50 mg	-
Dimethicone	50 mg (D)	50 mg (D)
Sorbitol Solution	-	1.25 g 70% (w/v)

Important Information of the samples:

	Sample 1	Sample 2
Mass of the sample:	0.2 ± 0.005 g	0.85 ± 0.15 g
Mass of minimum recommended dosage:	1.124 g	5 mL (Assume 1mL~1g)
Molarity of NaOH:		

Q.1 In the sample solution prepared by you for titration, write the major chemical species present in the flask

- a) At the beginning (when you have not added HCl)
- b) After adding excess HCl to the sample in the flask, assume only active ingredients react.
- c) After the endpoint (where titration with NaOH is just complete)

Q.2 Find the amount of NaOH (in millimoles) consumed in each titration written below. Show all steps of calculation.

Q 3. Based on the calculated data for Q.2, answer the following with proper reasoning.

- a) What is the amount of **HCl (in millimoles)** neutralised by the **antacid sample-1** during titration? Show calculation stepwise.

- b) What is the amount of **HCl (in millimoles)** neutralised by **antacid sample-2** during titration? Show calculation stepwise.

Q 4. Mass effectiveness is defined as millimoles of HCl neutralized by a sample divided by the mass of the sample. Find out the mass effectiveness for both samples. Take the values corresponding to 1 tablet and 5 g of suspension for calculation.

Q 5. Consider a hyper-acidic stomach of 500 mL in which the HCl concentration is 0.025 M. You have to prescribe a dosage for the antacid samples that you analyzed such that the concentration of HCl is reduced to a more normal level of 0.00030 M? How many tablets/volumes of the antacid sample will you prescribe? Use ANC corresponding to 1 tablet and 5 mL as one dosage and express in terms of their multiples.

Q 6. In the previous trial of this experiment, the following possible procedural changes were made. Explain how it would have changed the titre value of NaOH.

Note: For uniformity, answer the below questions for the tablet sample.

- a) A student was in a hurry and skipped heating the solution before titration with NaOH solution

- b) A student added an extra 5 ml of HCl to the antacid sample by mistake and the rest of the procedure was repeated.

- c) A student boiled the antacid solution for 20-25 minutes. So, to cool it down, 10 ml of distilled water was added before titrating it with NaOH solution

- d) A student after adding water to the tablet started swirling it vigorously thinking it would increase the solubility. Some of the solution was split out so he added a 50 mg antacid sample and then followed the same procedure. (Note: HCl was still in excess)

Q 7. Now that you have performed the experiment, what do you think are the possible reason(s) for not doing a direct titration of the antacid sample? Please write the experimental observation to support your reasons; if you say it's because of reason 'A' explain how you conclude it from the observation of 'A' during titration. There can be one or more reasons.

Reasons	Experimental Observation

Post-lab activity:

Through this activity, we will try to understand the reaction between antacid and HCl and how pH changes. A fixed amount of antacid sample will be taken and 1 mL of 0.1 M solution of HCl will be added to the antacid solution. Since it's a weak base and strong acid reaction pH will change, which can be easily monitored through indicators.

Q 8. Please fill in the pH range for the activity at different stages of titration performed with a suitable indicator. Note that the amount of antacid is adjusted to have an endpoint in the range of 8-15 mL. Consider it as a weak base and strong acid reaction:

Stage	pH range
1. Antacid solution	
2. When 2-3 drops of HCl are added to the antacid solution.	
3. When the endpoint is achieved in the titration	
4. After 2 min of the endpoint	
5. After 5 min of the endpoint	
6. After 10 min of the endpoint	

Q.9 In your opinion, which of the following indicators would be suitable for observing the reaction between antacid and HCl? Explain your answer in brief.

Indicator	pH range for colour change
A	3.1(red)-4.4(yellow)
B	6.0(yellow)-7.6(blue)

Activity:

A similar amount of sample is taken (consider that the samples have a similar amount of active ingredient) in separate beakers and 4/5 drops of Methyl Orange Indicator is added. We will add 1 mL of 0.1 M solution of HCl to the sample solution and observe the colour for 15 minutes. The colour of the solution will indicate how the pH changes with time. The demonstration will be shown to you, please note down the colour of the solution at different time intervals:

Samples	Initial colour	t = 0 (after adding HCl)	t = 5 min	t = "?" (colour change)
Sample-1				
Sample-2				

Q 10. Answer the following questions, explain your answers in brief.

- a) For sample 1, on adding HCl, the colour of the solution changed instantly but after some time, the solution colour changed again. Why do you think it happened?
- b) Is the time for colour change the same for both samples? If yes/no, then why? Please note that the amount of active ingredients taken is the same in both samples.
- c) What will be the likely observations at the end-point in direct titration? Explain your reasoning.
- d) Do you think it is possible to directly titrate the antacid sample with HCl? Justify your choice. You can refer to the observations of both post-lab activity and lab.

Q 11. Data Reflection:

	Solubility in H₂O	ANC value (min. recommended dosage)	Mass effectiveness (per gram)	Dosage (in grams)
Sample 1				1.145-2.29g (1-2 tablets)
Sample 2				5-10 g (5-10 mL)

a) You can try to analyse:

- i) how a single parameter is changing in different samples and why?
 - ii) Is there any correlation between different parameters? If yes, how can you prove that based on the information of the sample and data from the experiment?
- b) Both the samples you analyzed have similar types and amounts of active ingredients. Speculate whether their action as an antacid will be the same or different in the stomach. Consider other ingredients and solubility parameters.

Q 12. Consider the situations given below for the antacid's reaction with HCl (these are hypothetical situations). For each situation, explain whether you can calculate the ANC value by direct titration with a standard solution of HCl or by back titration (that is adding excess of HCl and then titrating it with a standard solution of NaOH).

- a) The antacid is soluble in water but the reaction with HCl is kinetically slow.
- b) The antacid is soluble and reacts rapidly with HCl. There can be two different possibilities:
 - i) The exact stoichiometry of the reaction of the active ingredient with HCl is known.
 - ii) The exact stoichiometry of the reaction of the active ingredient with HCl is not known.
- c) The active ingredient of the antacid is moderately volatile when kept open in the air

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Appendix-F Feedback Analysis by external individuals

a) Trial 1

Questions	External Individual-1	External Individual-2
Parts of the module that students liked.	<i>Design of module; pre-lab, lab and post lab, Questions discussed in pre-lab and post-lab activity.</i>	Discussion on each part of the experiment through questions. The language was easy for them to understand.
Challenging part of the module for students	Concept of ANC, Some of the pre-lab and post -lab questions. Difficulty in understanding the end point in the titration.	Post-lab discussion specifically some calculations. To note the end-point carefully seems to be a challenge
Students learning from the experiment	Application of titration in real life. Discussion of ANC, mass effectiveness helped students to understand the factors to be considered before choosing an antacid. Pros and procedure of back titration.	They learnt the concept of back titration and how to perform it. They further learnt it to apply it in the case of ANC of antacids.
Students perception of their learning experience	Learning through a discussion based session because most of the responses are around the post lab and pre lab discussion part. A clarity on what steps they are following in the lab and what is the necessity of that. Students also understood the importance of planning experiments.	They were paying more attention to each step and thinking through the pre-lab and post-lab discussions. It is also mentioned by some students that it was difficult at first during pre-lab discussion but by the post-lab discussion they could reach clarity.
Difference b/w this module and regular lab	Discussions are rarely done, the gap between the practical and the concepts.	It is not the usual 'following a dictated procedure' activity for them but they are aware of why and how of the experimental steps.

b) Trial-2

Questions	Coder-1	Coder-2
Parts of the module that students liked.	Lab session and post lab discussion, Design of module	Discussions during the pre-lab and post-lab session through questions. Most of the students think 'performing the experiment' was the best part for them.
Challenging part of the module for students	Questions discussed in the pre lab and post lab session. Calculation part	Most of the students find post-lab questions fairly difficult, specifically calculations. Students also said that with guidance, they were able to arrive at answers.
Students learning from the experiment	Process of back titration. Which antacid is good in terms of relief time? Chemistry behind antacid action	Student answers point towards learning about titration, back titration and applying it to the concepts related to antacid and its dosage.

Students perception of their learning experience	Design of the module is appreciated by the students. Students understood the importance of discussion before and after the lab session. The way the instructors executed the module helped students to think about a particular concept in a deeper manner and increased confidence in students to deal with the lab activities.	Students perceive that they were able to think much more openly and reach a clear understanding of each part of the experiment.
Difference b/w this module and regular lab	Regular lab sessions focus on the practical part rather than discussion. Division of modules into 3 parts and the implementation of modules in multiple days rather than a single day helped the learning process of students.	Students reported it was different in a way that they didn't have to perform the experiment simply after reading the procedure, they had the chance to ask questions, and arrive at a clear understanding of the procedure before performing the experiment itself.

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