Problem-Based Learning in Undergraduate Chemistry Laboratories in India

A Thesis

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by

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Declaration

This thesis is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions.

The work was done under the guidance of Professor Savita A. Ladage at the Tata Institute of Fundamental Research, Mumbai.

Sujatha Varadarajan

In my capacity as supervisor of the candidate's thesis, I certify that the above statements are true to the best of my knowledge.

Savita Ladage

Savita Ladage

Thesis Supervisor

Date: 19 - 09 - 2023

Dedication

To

The Cause of Meaningful Education

Those Who Look Forward to Reform in Chemistry Lab Education

My Parents and My Family

Acknowledgements

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Publications

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Abstract

The research study presented in this thesis has explored the feasibility of implementing an inquiry-based approach in undergraduate chemistry laboratories in the Indian context. An inquiry-based approach helps students to engage with higher-order thinking skills and catalyze the process of becoming independent investigators in the experimental domain. Inquiry approaches are widely recommended in the chemistry education research literature. Additionally, the New Educational Policy (NEP-2020) released by the Indian government also recommends shifting from conventional pedagogical practices to inquiry approaches. However, there are challenges in adapting inquiry-based approaches owing to the diversity in the educational contexts. That raises the need for a dedicated research-based approach to implementing such pedagogies. To the best of my knowledge, sparse work of the kind that I wanted to explore exists in the Indian context.

The study focussed on colleges affiliated with the university system in India with the premises that, a) there is a need to present a holistic approach to laboratory experience by integrating different domains of chemistry, and b) it is essential to provide adequate time for the learner to engage with the inquiry-based tasks to learn the process of inquiry.

The chemistry education research(CER) literature review helped in understanding the important goals that the researchers consider to be central for imparting laboratory education at the undergraduate level. These goals are based on Novak's theory of meaningful learning and are related to cognitive, psychomotor, and affective domains of learning in the laboratory. The other thrust of the literature review was to understand various inquiry-based instructional styles as an alternative to the expository style widely adopted in conventional undergraduate chemistry laboratories.

In addition to gathering a broader understanding of laboratory education through CER literature, three sub-studies were carried out to better understand the local context. These sub-studies included a) an analysis of lab manuals, b) a survey to understand students' and teachers' preferred goals of lab education, and c) a pilot exploratory study on the implementation of the inquiry module.

The results of the analysis of representative lab manuals prescribed by Mumbai and SPPU universities suggested that the colleges affiliated with these universities (approx. 1500 colleges) predominantly follow conventional style, a "cookbook" approach and was further substantiated by interviews with two of the authors. The survey indicated that the students prefer problem-solving to be the goal whereas the teachers thought sustainable practices and concepts should be the preferred goals of laboratory learning. The responses by students who participated in the pilot study were encouraging, however, the exploratory study suggested the need for scaffolding the inquiry learning in the laboratory.

Considering the results from the survey and the exploratory study, a short course on indigo dye was designed for the main research study. This short course adopted an incremental approach to introducing inquiry levels and it included a scaffolded problem-based learning (PBL) module as a higher level of inquiry.

It was important to first understand the role of the scaffolds developed for the PBL task before understanding the feasibility of implementing the short course with incremental inquiry approaches. Thus, Study 1 explored the effect of scaffolds on the experimental design devised by students for the PBL task through a quasi-experimental approach. The PBL module was based on wastewater treatment generated through the indigo dyeing of yarns. Scaffolds such as a precursor task, reading material, and structured group discussion were designed to support students' self-directed learning. The PBL task was implemented in four workshops (n = 75 students), with different groups of students. This study was informed by Kolb's Experiential Learning Theory.

Study 2 focused on understanding the science practice skills imparted during the implementation of the indigo short course. The course included a set of four tasks related to the synthesis of indigo dye, dyeing of yarns, analysis and treatment of wastewater generated. These four tasks had an incremental approach to inquiry learning. Study 2 was conducted using a case study approach with a group of 12 students and the lab reports generated were analyzed in detail to understand the gain in science practice skills.

The results of these two studies indicated that the scaffolds help students in devising an experimental design and the incremental approach to laboratory learning enhanced the science practice skills of the students. Both, the scaffolds and the incremental inquiry approach, favour the smooth transition of students from conventional to inquiry laboratory instruction. Such support is indeed helpful to students in their learning process, in a complex learning space such as the laboratory, where the students need to integrate the learning of science process, chemistry content and skill development.

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Chapter 1

Introduction

Laboratory education is very central to undergraduate chemistry courses and requires a considerable investment of human resources, infrastructure, and time. The lab courses also have significant weightage in terms of assessment. Presently, chemistry laboratory education follows a conventional approach, especially in state colleges affiliated with the university system in India. In this style, students precisely follow the given procedure as in a cookbook to perform experiments thereby having less opportunity for cognitive engagement. Though collaborative work is known to benefit students academically, psychologically and socially as well (Lu et al., 2014, Laal and Ghodsi, 2012, Zoller and Pushkin, 2007), they are expected to work individually without engaging in discussions with peers in the conventional style. Thus, chemistry laboratory space provides ample opportunities for educational research that can suggest possible ways to enhance learning in the laboratory through inquiry approaches.

The research study presented in this thesis is situated in the Indian context and explores ways to help students transition from conventional labs to inquiry-based laboratories. The objective of the study was to understand the feasibility of implementing an inquiry-based approach with a focus on Problem-Based Learning (PBL) in undergraduate chemistry laboratories.

The National Education Policy (NEP) 2020, recommends integrating student-centric and inquiry-based approaches as a part of educational practices at the undergraduate level. In addition, many undergraduate colleges are getting academic autonomy which gives them the freedom to frame their curricula. In the light of such background, this study is the need of the hour for a research-based approach to introduce inquiry in the regular chemistry labs of colleges.

To understand chemistry laboratory education in the Indian context and to gather first-hand experience about the implementation of PBL-based lab tasks, an exploratory study was conducted. Based on the understanding from this pilot study, the main research study was planned. The developmental work of the study involved designing a short lab course with indigo dye as the central theme to introduce inquiry and PBL. To support the learning in the PBL environment, scaffolds were planned. Two studies were conducted. Study-1 explored the role of scaffolds in helping students arrive at the experimental design for the PBL experimental module. Study-2 explored the science practice skills acquired by students as they moved through a course that progressed with incremental inquiry levels. The following section presents the motivation for the study and outlines the organization of the thesis chapters.

1.1 Motivation for the study

The motivation to undertake a research study on chemistry laboratory education stems from my own experiences. The experimental work that I carried out as an undergraduate student was primarily driven towards getting the correct result. Whenever I used to get erroneous result, I failed to understand the reason. This experience used to affect my confidence in performing laboratory experiments. When I took up a sought-after career in teaching, I saw students too struggling with similar issues.

Later, I got the opportunity to work with experts that helped me gain insights into various pedagogical styles. I got deeply interested in inquiry-based pedagogy and observed that the students who were taught in this style were getting interested in learning. This observation was encouraging for me.

My formal training in Environmental Chemistry interested me in experiments in this domain as they are intricately connected to everyday life. Thus, a strong inclination towards designing inquiry activities navigated me to this research work involving inquiry and chemistry laboratory. I thought of exploring the ways to enhance laboratory investigatory skills in students by integrating both cognitive skills (e.g. planning, critical thinking, decision-making, data handling, etc.) and experimental skills (e.g. procedural, manipulative skills, etc.). With a substantial investment of time and resources in chemistry laboratories, a natural question is, how could students' laboratory experiences be improved? I engaged with this larger question when I got a chance to explore learning in laboratory space during my doctoral study.

The details of my work on introducing inquiry and PBL in an undergraduate chemistry laboratory are elaborated in this thesis and the following section presents the organisation of the thesis in brief.

1.2 Organization of the thesis

The thesis consists of nine chapters. This first chapter is short and gives an introduction and motivation for the study. Chapter 2 presents Chemistry Education Research literature review that is related to the goals of undergraduate chemistry lab education and the various instructional styles adapted globally. The third Chapter analyzes two prescribed laboratory manuals, in use by colleges in the Mumbai region and colleges in the Pune region, both regions located in Maharashtra, India. This Chapter also presents an analysis of a survey questionnaire on the preferred goals of chemistry lab education that was administered to chemistry teachers and undergraduate students. Additionally, the chapter also presents the exploratory study aimed at understanding the feasibility of introducing inquiry in an undergraduate chemistry laboratory.

The next chapter, Chapter 4, discusses the conceptual and theoretical framework related to inquiry-based pedagogy with a focus on problem-based learning. Chapter 5 presents the conceptualization and detailed description of the design of the short course. Aspects such as research design, development of instruments, its validity, and reliability are discussed under the research methodology in Chapter 6. Chapter 7 presents the results from Study-1 aimed to investigate the role of scaffolds in devising experimental design. Chapter 8 describes the results of Study-2 on implementing the Indigo inquiry module as a short course. The last chapter, Chapter 9, summarises the research work and its findings, and the implications for curriculum designers, researchers, and practitioners. Limitations of the study and possible future directions are also presented in this last chapter.

Chapter 2

Literature Review

2.1 Overview of the chapter

The chapter presents a review of chemistry education research literature (CER) for the stated roles and goals of undergraduate chemistry laboratories. The chapter discusses various instructional styles both the conventional and inquiry-based approaches which are followed in laboratories across various universities at the global level. In addition, the chapter presents a dedicated review of the Problem-Based Learning (PBL) instructional style adopted in undergraduate chemistry laboratories.

2.2 Roles and goals of chemistry laboratory education

Chemistry lab instruction was introduced in formal education at the undergraduate level to enhance observational skills and to help students verify the concepts (Elliott et al., 2008, Leicester and Klickstein, 1971, Davis, 1929) in the 19th century. Laboratory programs since then have been an integral part of undergraduate chemistry education. The literature on laboratory education suggests that the conventional laboratory program aims, first, to develop laboratory skills and second, to verify the concepts learned in theory (Reid and Shah, 2007; Domin, 1999a). Concepts are verified by following a well-laid-out procedure to get the correct result (Kirschner, 1992). Such an approach focuses on the final correct result rather than on the process skills. Analysis and evaluation of errors and variations inherent to any experimental procedure are generally left out of the scope of discussion. Further, students need to view the theory and practice of chemical concepts as very much intertwined with each other as chemistry is an experimental science and many theories are generated through laboratory experiments(Bennet et al., 2009). The current chemistry laboratory course mostly offers a delineated view of the two.

In the past few decades, researchers have devoted time to understanding what should be the goals of chemistry laboratory education and how to achieve the intended outcomes. Some researchers have in fact raised questions on the educational effectiveness of laboratory education for want of clearly stated goals and learning objectives (Bretz, 2019; Bruck and Towns, 2013, L. D. Bruck and Towns, 2009; Hofstein and Mamlok-Naaman, 2007; Reid and Shah, 2007). Apart from a clear articulation of the overall goals, Boud et al., 1989 argue that the aims and objectives of laboratory education should also be precisely stated and communicated to students to clarify what they are expected to do in the lab. If students are unaware of these, the chances of meeting the learning objectives is reduced (Kirschner and Meester, 1988).

The laboratory is an expensive learning environment due to the need for dedicated infrastructure such as equipment, chemical, glassware, trained instructor, etc.(Bretz, 2019). The number of hours spent in the undergraduate laboratory ranges from 300 to 400 hours and this quantum of time spent in the laboratory is almost 40% of the total time in higher education (Berg et al., 2003). Thus, researchers have tried to address the concern about not stating the goals and aims of chemistry laboratory education. The research community has warranted the need to understand the nature and scope of learning in the laboratory by raising questions such as, what is distinctive in the laboratory that cannot be achieved through the curriculum meant to be delivered in a lecture mode? In other words, they ask, why do we have laboratory work in the curriculum (Seery, 2020)?

There are several viewpoints presented by researchers related to what the goals of laboratory work should be like. Some educationists and educators are inclined towards fostering cognitive skills through laboratory education while others contend the need to develop laboratory techniques and skills as the foremost role of laboratories. Yet another group of researchers thinks scientific skills should be given priority. Table 2.1 summarizes the objectives and outcomes of laboratory learning as proposed by various researchers.

Table 2.1: Goals and outcomes of chemistry laboratory education

Author	Goals of laboratory	Proposed/possible outcomes
Leman and Burcin(2010)	Understanding of scientific concept, improving cognitive, skills and positive attitude	Enhanced achievement in conceptual assessments
Hofstein and Mamlok (2005)	Understanding of scientific concepts, Interest and motivation, science practice skills and problem-solving abilities, scientific habits of mind, nature of science.	Improved cognitive abilities
Reid and Shah (2007)	Skills related to learning chemistry, practical skills, general skills, scientific skills.	Thinking scientifically
Buntine et al. 2007	Discovery of knowledge through experimentation	—NA—
Hoftein, Shore and Kipnis Hofstein et al., 2004	—NA—	Improved cognitive abilities
Carnduff and Reid (2003)	Practical skills, general skills, intellectual stimulation	—NA—
Seery (2020)	How to do chemistry, deduction/interpretation, appreciate the source of evidence, learn to devise an experiment	—NA—
Bruck and Towns (2009)	Inquiry skills, laboratory skills, experimental design	—NA—

In an attempt to understand what chemistry faculty perceive as the goals of undergraduate laboratory education, Bruck and Towns, 2013, categorize the goals based on thinking, feeling and doing.

These goals suggested for chemistry laboratories in the literature can be classified into cognitive, affective and psychomotor domains as is given in the Taxonomy of Educational Objectives (DeKorver and Towns, 2015; Krathwohl et al., 1964). In addition, Bretz, 2001 describes Novak's theory of meaningful learning. *"Novak's theory of education, known as Human Constructivism, states that "meaningful learning underlies the constructive integration of thinking, feeling, and acting, leading to human empowerment for commitment and responsibility."* The learning is intrinsically motivated when the learner can make sense of the integration of the new knowledge with the prior knowledge resulting in higher positive results. Based on these three domains as the criteria, researchers' view on the goals of laboratory education is presented in the following section.

Tables 2.2, 2.3, and 2.4 summarize the literature survey on various goals as suggested by researchers who are involved in both curriculum design and implementation (Abraham, 2011; Bruck and Towns, 2013).

Table 2.2: Cognitive goals

Subcategories	Descriptions
Overall learning goals	• Students should be able to design experiments and analyze and interpret data to solve a given problem situation. • Chemistry experiments should enhance awareness about environmental problem and their possible solution. • The laboratory should show chemistry as a challenging subject worth pursuing as a career option.
Epistemic goals	• Experiments should help to confirm a fact/law/theory • Experiments should allow students to come up with some new understanding/theory/facts. • Experimentation should consider the inherent errors to be taken into consideration. • Experimentation should be a better way of gathering understanding about a phenomenon than listening to a lecture. • The laboratory should help to carry out empirical testing of chemical facts.
Chemical concepts	Student should, • Get familiar with important chemical facts, and strengthen understanding • Learn to apply lecture content/theory in the laboratory • Get a better understanding of a theoretical concept through experiments
Scientific skills	Students should develop abilities to, • Ask questions/identify variables/hypothesize • Formulate experimental design • Analyze and interpret data to draw inferences • Explain the experimental observation • Justify the conclusions • Communicate findings

Table 2.3: Affective goals

Subcategories	Descriptions
Affective goals	Laboratories should help students to, • Enjoy working in a team and collaborating. • Think that doing experiments is fun and enjoyable. • Remain motivated till completion. • Think experiments are not tiring/tedious. • Enhance confidence to work with chemicals and instruments. • Develop patience and perseverance.
General skills	Laboratories should help students to learn, • to be cooperative with team members. • mathematical skills needed for experiments. • to better communicate with friends and faculty. • to manage time for the given task. • to report findings through written and verbal communication.

Table 2.4: Psychomotor goals

Subcategories	Descriptions
Practical skills	Laboratory should help students in, • Developing a procedural understanding, • Learning instrumentation and handling of equipment • Understanding safety measures that are to be followed in the laboratory. • Seeing abstract chemistry happening in real.

Frameworks for learning in the laboratory

Kirschner and Meester, 1988 emphasized cognitive goals. They suggested that the laboratories should aim at developing scientific skills such as formulating a hypothesis, solving problems, using knowledge and skills in unfamiliar situations, designing simple experiments, interpreting experimental data, and remembering the concepts of the experiment over an extended period.

Carnduff and Reid, 2003 categorized the goals of chemistry laboratory education as practical skills, general skills, and intellectual stimulation. According to them, practical skills should include understanding in carrying out procedures, using instruments, making observations, etc. which may be subject-specific. And, the general skills should include team working, time management, communication, presentation, data processing, designing strategies, problem-solving which can be extended beyond the chemistry laboratory. The cognitive objective of intellectual stimulation is related to finding connections with the 'real world', raising enthusiasm for chemistry, etc. Reid and Shah, 2007 extended this list and suggested that specific skills relating to learning chemistry and scientific skills (observation, deduction, and interpretation) should also be the additional objectives of the laboratory work.

Tarhan and Sesen, 2010 consider that the laboratory provides an opportunity for active learning with the goals of developing students' understanding of scientific concepts, improving cognitive skills, and positive attitudes.Tarhan and Sesen, 2010 work suggested that instruction supported by laboratory experience increased students' achievement in topics such as acids and bases.

Seery et al., 2019 suggests that there is a need to have the goals well aligned among the faculty, curriculum, and the students' expectations. Any misalignment would defeat the purpose of laboratory education. Of the given objectives of the laboratory, some instructors may choose to use laboratory space to support the learning of chemical concepts while others may have the development of inquiry or scientific skills as the objective. Seery, 2020 supports and elaborates his views on the laboratory as a place to learn to do chemistry, and contests some of the goals suggested in the literature. For example, he supports Woolnough and Allsop, 1985 idea of not using practicals as a strategy for teaching science concepts. Arguing against the notion of utilizing the space for developing transferable skills such as teamwork, time-management, he says that these are not specific to laboratory learning but rather should be a part of the entire undergraduate curriculum. He contends that the laboratory is an expensive environment to teach theory or to make chemical concepts and ideas real; because there is no basis on which a specific theory can be selected or not selected for laboratory instruction. According to him, the laboratory curriculum should focus on helping students progress with the ability to do chemistry through the years of their undergraduate degree (Seery et al., 2019). Seery, 2020 further comments,"*Lab is a place where a very specific goal unique to that environment is achieved.... The laboratory is part of a chemist's identity, but as educators we need to be much clearer on its pedagogic basis and the advantages that laboratory work add to our curricula.*" While lectures are a place for acquiring scientific knowledge, laboratories become a place for learning the process of acquiring this knowledge i.e., how to do chemistry (doing science).

The chemistry laboratory should be a place to learn to deduce/interpret, appreciate the source of evidence, and learn to devise an experiment.

Based on the learning goals of laboratory education as suggested in the CER, it is important to understand the design of the instructional styles that harness these goals. Laboratory instruction has the potential not only to clarify and verify concepts; but also to enhance the inquiry ability and to expose students to Methods of Science (Pea and Collins, 2008). An inquiry laboratory has the cognitive objective of allowing students to pose hypotheses, design experiments, make predictions, choose dependent and independent variables, and decide how to analyze results. These aspects should be the emphasis of laboratory education (French and Russell, 2002; Grushow et al., 2022). Supporting this viewpoint L. D. Bruck and Towns, 2009, place a highly regarded position for such inquiry-based instructional styles. Further, they express the need for developing- a) the foundational knowledge for engagement in inquiry activities, b) appropriate laboratory skills, c) independence in formulating experimental procedures, method of analysis, and defence of the result. Such an approach to laboratory learning, they suggest, helps students to remain motivated as students want to see the outcome of something that they have planned.

With the enhanced understanding of what can be achieved through laboratory work, a shift in the focus of the laboratory curriculum from verification to inquiry experience is recommended in recent times. Seery, 2020 claims that laboratory is a complex learning environment that needs the integration of knowledge, skills, and attitude as well. Further, students' affective domains such as motivation, emotions, and expectations should also be considered, suggests Seery, 2020.

Different instructional styles can be adopted to achieve the goals suggested by researchers. The following section discusses various instructional styles in detail.

2.3 Instructional styles

Domin, 1999a classified the laboratory instructional styles into broad categories based on the outcome, procedure, and approach (deductive/inductive). Expository, discovery, open inquiry, and problem-based learning were broad categories and these are listed in Table 2.5.

Table 2.5: Instructional style followed in chemistry laboratory (Domin, 1999a)

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

2.3.1 Expository Instruction

Expository instruction is deductive in nature; i.e., laying emphasis on utilizing prior knowledge for performing experiment by teaching the concept in the lecture prior to carrying out the related experiment in the lab. The procedure for the experiment is given to students and the outcome is known to the instructor and students as well. The result obtained by students in an experiment needs to match the expected result. The expository method emphasizes on verification of existing knowledge. The learner is passive and is not exposed to the scientific method. This instructional style gives students excellent training in lab technique claims Mauldin, 1997.

Domin, 1999a highlights the multiple benefits offered by this method of instruction. He claims that the advantage of this method is, a large group of students can simultaneously be engaged with minimum resources of equipment at a low cost and more importantly within 2 to 3 hours of laboratory time. The ease of lab preparation and instruction to teaching assistants is also cited as the advantage of this style (Dunlap and Martin, 2012). The author further claims that clarity in the way teaching is carried out leads to increased self-confidence in students for performing the experiments. Some researchers acknowledge the important role of this instructional style in acquiring basic experimental skills and techniques (Bertram et al., 2014; Burnham, 2013; J. Lewis, 2002). Ault, 2004 in his commentary on what's wrong with cookbooks suggests,

"Recipe and procedures are a point of departure, used thoughtfully, they can develop skills and provide insight.". . . . Now why is it that when I'm showing my grandchildren how to cook I'm quite happy to get out a recipe, but when I'm showing my students how to operate in the lab I'm supposed to hide the book?

This style often receives criticism for being a cookbook way of carrying out the experiment. Students are provided with the stepwise procedure to carry out the experiment which is less engaging cognitively, claims Domin, 1999a. Highlighting the shortcomings of this instructional style, Tobin, 1990 claims that the cognitive demand for this lab is low as students' efforts are to obtain the correct result than in planning and organizing the experiment. Students do not get an understanding of the open-ended nature of science or the tentative nature of scientific explanations (Mauldin, 1997).

Many researchers think that this style does not expose students to the true nature of scientific experimentation and lacks mindful engagement (Chopra et al., 2017). The expository style receives criticism also because the goals seem to be focusing on the psychomotor domain with little emphasis on the cognitive domain.

Alternative to expository instruction style

There are two possible alternatives to expository instruction, namely, guided inquiry and open inquiry. There are many instructional styles such as the discovery, PBL, PLTL etc. that fall under the guided inquiry category and these are explained in the following section.

2.3.2 Inquiry-Based Learning

Discovery Style Instruction

In the discovery method, students are given the procedure for which they don't know the outcome; however, it is known to the instructor. This method adopts an inductive approach with an emphasis on data interpretation and in this process students make the so-called discovery of the concept. The instructor guides the students toward the desired outcome by giving directions. Students adopt the role of a discoverer which has some motivational value. Discovery learning illustrates the scientific method and evidence exists that suggests students are better engaged in this type of lab than the expository labs (Dunlap and Martin, 2012).

This instructional style is critiqued as students do not have the basic knowledge of the material to be learned i.e. students are not conceptually prepared for making a discovery. Domin, 1999a argues that the discovery of a new concept without any prior theory or knowledge is less likely. Also, the possibility that something that lends itself for discovery has an equal chance for it to be not discovered. Additionally, going by the definition of discovery, if one student group discovers a concept through the given experiment, what others arrive at is no longer a discovery. It is time-consuming and training of teaching assistants may be a further deterrent to this style. However, it may be motivational to students for having initiated an experiment to make a "discovery" (Domin, 1999a).

Process Oriented Guided Inquiry Learning (POGIL)

Process Oriented Guided Inquiry Learning (POGIL) gives adequate guidance to inquiry learning (Daubenmire and Bunce, 2008; Stegall et al., 2016), offers support to students and guides students in the direction of the expected outcome. It is a learning cycle where inductive and deductive approaches are used subsequent to one another to arrive at a pre-determined outcome. It is based on the nature of learning and learning strategies. The collaborative work in small teams and a student-centric approach are the other advantages of POGIL. POGIL style is applicable for experiments that can generate data for the inductive and deductive cycles. The facilitator is expected to guide students' exploration in their construction of understanding and facilitate higher-order thinking. The objectives of this approach are to improve learning skills such as information processing, communication, critical thinking, and problem solving (Latimer et al., 2018; Moog et al., 2006).

The learning cycle of POGIL includes exploration, concept invention followed by application. Students get exposure to phases of this cycle through carefully crafted questions for recognizing patterns in the given POGIL material. The POGIL material may include, pictures, tables, equations, graphs etc. The second phase involves recognizing the relationship and the construction of ideas in the concept. In the next phase, this concept is given in a new situation which has to be analyzed thus augmenting the understanding (Rodriguez et al., 2020). The emphasis is on the mastery of content and development of process skills (Eberlein et al., 2008).

In the experimental domain, students work through multiple data cycles. They answer the guiding questions, formulate a hypothesis, run an experiment and analyze the resulting data. Students working in small groups make their own decisions on the experimental parameters such as concentrations and quantities of chemicals, number of trials etc. POGIL experiments rely on data pooling by students and are often carried out simultaneously by the whole class (Stegall et al., 2016). One of the key features is the roles that are assigned to students working in small groups which enhances the process skills while they engage in problem-solving. These include the manager, recorder, presenter and reflector. In their review work on POGIL activity, Rodriguez et al., 2020 bring forth some of their findings which include that assessing the process skills is difficult as students are not very clear about the definition of cognitive process skills and how to recognize engagement in these in the laboratory (Reynders et al., 2019). Further, they conclude that despite the proven effectiveness of the POGIL approach, universities continue instructor-centred approaches. Questions that are a part of the POGIL material should be delicately balanced by not being over-guided and easy. Though POGIL creates a classroom environment that is well received by the students (Brown, 2010), there exists a possibility that even a small variation in the implementation will create unintended differences in students' outcomes (Daubenmire and Bunce, 2008).

Peer Led Team Learning (PLTL)

This is yet another popular alternative instructional approach that provides an environment for students to engage in problem-solving under the guidance of peer leaders leading to intellectual discussions (Snyder and Wiles, 2015). Students who have done well in the class previously, lead the workshops. The meeting of students and the peer leaders happens weekly once providing an opportunity for active engagement and cooperative learning strategy. A study by Wilson and Varma-Nelson, 2016 suggests that the students undergoing this support for their experimental work could describe the experimental procedure better, and had awareness of factors as well as the overall goals of the lab. The length of the responses and the report also suggested better clarity and accuracy of chemistry. Lewis, 2011 work suggests that there is a strong potential for PLTL to retain students from dropping out of the course because there is improvement in the pass percentage despite the same rigour. This happens because PLTL works within the zone of proximal development as described by Vygotsky (Lewis, 2011).

Problem-Based Learning, (PBL)

Problem-based learning is one of the alternatives in which a problem is given to the students and the necessary materials are provided to help students succeed in finding the solution. The procedure is student-generated and the outcome is pre-determined for the instructor. Though it is deductive in nature, the concepts are strengthened through their application in new contexts (Byers and Eilks, 2009). The focus of this style is on helping students develop a testable hypothesis rather than on obtaining a correct result. However, it is contended that the beginner should be oriented in the direction of problem-solving. The problem acts as a vehicle for learning and hence the process and content both are important goals of this instructional style. During this process, White, 2002 suggests that students get ample opportunity for their creative engagement in problem-solving and obtain a greater insight into course material. Further, this style cognitively engages students to think about what they are doing and why are they doing it, thus fostering higher-order thinking skills. If a student is successful in a PBL activity, it is indicative of student's understanding of the concept. Duch et al., 2001 describe PBL to be a composite of context-based and inquiry-based instructional methods. Baran and Sozbilir, 2018 highlight the difference between context-based learning and PBL. PBL is situated in a context, however, CBL need not pose a problem in finding a solution, unlike PBL. They contend that "*If a problem is presented in a real-life context, the context-based problem is formed*". While there are a lot of similarities between problem and project-based learning there is a characteristic feature that distinguishes the two instructional styles. Guo et al., 2020 suggest that project-based learning includes a driving question, focuses on learning goals, collaborative participation in educational activities, collaboration among students, the use of scaffolding technologies, and the creation of tangible artefacts. Among all these features the creation of artefacts that solve authentic problems is most crucial, which distinguishes PjBL from other student-centred pedagogies."

2.3.3 Open Inquiry Learning

Domin, 1999a in his paper defines open inquiry as an inductive approach. In this approach, students have to devise an experimental procedure to investigate a question for which the outcome is undetermined. Since the procedure is student-generated and the emphasis is on the process and not on the result, students get less direction from the instructor. The instructor does not have control over the direction of the flow of investigation, thus, the pedagogical viability is not clear. Thus, this style is not adopted extensively in undergraduate labs though it adheres to authentic scientific practices.

Table 2.6 summarizes the various instructional discussed above with respect to approach, procedure, outcome, point of emphasis, disadvantages and advantages.

Table 2.6: Instructional styles

Instruction Style	Approach	Procedure	Outcome	Emphasis on	Disadvantages	Advantages
Expository traditional	Deductive	Given	Known to the instructor as well as students	Result, Verification,	Passive/Rote learning; no exposure to scientific method	Can handle large group with minimum Resources
Discovery	Inductive	Given	Predetermined for instructor	Interpretation of data; collaborative learning	Pedagogically problematic	Motivational to students, Ignores the need for prior theory
POGIL	Inductive Deductive Cycle	Given	Predetermined for instructor	Processes, skills, concepts, application	May not be applicable for all kinds of lab experiments	Complies with nature and strategies of learning,
PLTL	Deductive	Given	Predetermined for the peer leaders	Concept and problem-solving skills	Training of the peer leaders and a good people's skill by the peer leader a must	Supportive environment for active learning
Problem based	Deductive	Student Generated	Predetermined for instructors	Values diverse paths to problem-solving, collaborative learning	Time-consuming	Concepts strengthened through application in new contexts.
Open Inquiry	Inductive	Student Generated	Undetermined	Science Practice skills	Pedagogical viability unclear	Complies with authentic scientific practice

2.4 PBL as an instructional style in a chemistry laboratory

This section presents a review of the literature on PBL as an alternative approach to undergraduate chemistry laboratory courses.

There are multiple studies done to understand this pedagogical approach both in the classroom and in the laboratory setting. Results from such studies indicating a positive impact are encouraging. A couple of studies also talk about the challenges in implementation. This section provides a rationale for why PBL can be a promising alternative style to investigate.

These studies are categorized based on the impact of PBL on, a) the implementation of PBL in laboratory, b) the impact of PBL instruction on the cognitive domain, and c) the impact of PBL instruction on the affective domain. Research on PBL has used a qualitative, quantitative, and quasi-experimental design.

2.4.1 Studies on implementation of PBL in laboratory

Costantino and Barlocco, 2019 introduced a laboratory course on the synthesis of drugs through a PBL approach. The course was designed keeping in mind the constraints of students' prior knowledge and the available resources with respect to the number of students. There was a pre-lab component when students were given sheets with questions aimed at promoting thinking skills. The answers to these questions were expected to help students reflect on procedure of the experiments. Further, a template helped students in completing the report. The course had 13 units on theory and practical. At the end of the course, authors found that students developed-a) critical thinking ability, b) the competencies for the synthesis of a given compound, and c) the ability to use these data to plan and synthesize it in the chemistry laboratory.

In another study, the success of PBL is determined by the choice of the problem says Ram, 1999 who introduced PBL in her general chemistry lab. A real-world problem related to

water analysis was chosen for self-directed learning. Students generated multiple hypotheses to test for different pollutants and finally performed the analysis for nine water quality parameters by following the standard protocols gathered through a literature search. The implementation of the PBL task helped the author to gather evidence for student motivation, self-directed learning, depth of knowledge skills, and group dynamics. The self-study logs, self-evaluation logs, oral presentations, and posting in the campus computer network (Learnlink) were the data sources. The findings suggest that the students found the PBL task to be relevant, enjoyable, and motivating. The authors suggest that the PBL lab was found more meaningful than the usual labs as students took ownership of their learning.
While most of the implementation studies on PBL lab instruction assumed the development of lab skills to be an integral part, Mc Donnell et al., 2007 focussed on developing practical chemistry skills through PBL mini-projects. Students were supposed to complete this mini-project over five 3-hour laboratory sessions. Students had to develop the project plan based on the literature review and then carry out the risk assessment. It was then followed by experimental work to gather data and evaluate the results. Finally, the students had to write a reflective note on the findings and outcomes. The authors found that there was increased participation and improved class morale because of PBL approach. These findings were confirmed through an evaluation survey where students gave feedback. The authors contend that the PBL also helped students to be better prepared for the individual research project in the subsequent year.

2.4.2 Studies exploring the impact of PBL instruction on the cognitive domain

Shultz and Li, 2016 carried out a mixed-method study to understand the information-seeking behaviour of the students in a PBL lab. In the discourse analysis, they explored the process by which students find and use the sources of information. Their analysis of data indicated that students need explicit instruction. Students do not demonstrate information literacy skills (ability to gather relevant and required information) in the absence of explicit instruction and try to find the direct solution to the posed problem. Another study by Shultz and Zemke, 2019 involving interviews of students, suggests that the students recognized the need to use better resources. Google was preferred for their expedited search results.

In addition, they also failed to check the credibility of the online information source. Students struggle to apply their information literacy skills especially when the chemistry content was new and unfamiliar.

They propose that students should be instructed to develop information literacy, especially for PBL activities. A weak information literacy skill may affect the problem-solving skill thereby impacting the self-directed learning approach of PBL.

The science process skills related to PBL were studied by Gurses et al., 2007 through a pre-post science practice skill test. They found that the student's score was higher after the introduction to PBL. Their study also suggested that there is a strong positive effect in promoting problem-solving skills and their ability to transfer their skills to a real-world situation.

Sandi-Urena et al., 2011 conducted a very elaborate work to understand the effect of PBL on metacognition and problem-solving skills through a mixed-method approach and published the qualitative and quantitative results separately. They aimed at providing a conducive environment for social interaction and reflection to understand the learning in the academic chemistry laboratory. They provided an ill-defined inorganic chemistry problem (HAZMAT) related to the identification of a hazardous material that spilt on the floor due to an earthquake. They assessed the changes in the problem-solving abilities of the treatment group through software incorporating IMMEX (Interactive multimedia exercises) and a questionnaire with a metacognitive activities inventory. From their study they concluded that the learning environment created by the PBL approach in terms of a) opportunity for numerous smaller problems, b) no single optimal solution, c) encounter failures leading to aborting of the initial plan, and d) environment that promoted negotiation of beliefs, values, and goals, supported the development of metacognitive and problem-solving skills. To confirm their findings, they applied the research design again for a different PBL module (spectrophotometric determination of phosphate in cola) and they found that similar trends were followed.

Extending their work to understand the students' experiences, Sandi-Urena et al., 2012 carried out a qualitative study with 11 participants who participated in an open-ended interview. Their qualitative study corroborated their quantitative work. Further, they suggest that the students undergo three kinds of stages in the process of problem-solving. The first one is the Affective Response (could be resistance/ frustration) followed by acceptance. The second one is the Learning Experience where they come up with an accurate interpretation of the laboratory paradigm and the third is the Strategic Response which is related to taking charge of the required laboratory work. They contend that maximum learning takes place when a supportive environment is provided to students for challenging new experiences.

Tosun and Taskesenligil, 2013 conducted a quasi-experimental study with non-equivalent control and comparison group using a pre-post design to assess the effect of PBL on students' learning about solutions and science practice skills. They compared the PBL approach with the lecture method. The study related to the a) learning of concept, b) science practice skill and prevention of alternative conception. Eighty four students participated in this study; the data included an academic achievement test, a scientific processing skill test, and a scale for PBL. The quantitative analysis indicated that PBL was more effective with an increased level of accessing and using knowledge. There was an improvement in independent learning and problem-solving skills as well. However, the authors reported difficulty in setting up of heterogeneous small group of students. There were problems in establishing cooperation in the groups.

2.4.3 Studies exploring the impact of PBL instruction on the affective domain

Wellhöfer and Lühken, 2022 explored the factors that lead to intrinsic motivation in students through qualitative research with 12 participants. The PBL task involved the extraction of lithium from brine. The authors concluded that the students should experience an autonomous scientific process for intrinsic motivation and the problem itself should be engaging. The problem should have multiple problem-solving strategies giving the opportunity for multiple experimental designs as well. Further, laying importance on providing regular feedback, they suggest, that the students should feel competent in solving the problem.

Smith, 2012 planned ten PBL laboratory activities to help students from secondary school to undergo the transition to the University level. These activities covered various domains of chemistry including organic (re-crystallization, extraction, and TLC), inorganic chemistry (titration, pH, etc.) and physical chemistry (kinetics, Maxwell equations, etc.). The analysis of the five-point Likert scale questionnaire helped the author to infer that the PBL task met the aim for which they were designed. Their study suggested that the students developed practical skills and independent study skills. Students found the PBL activities interesting and scored better as compared to the traditional activities.

In the domain of analytical chemistry, the PBL module was developed to help students understand the significance of green chemistry. A quasi-experimental design with a control and treatment group was planned to understand the outcome of the implementation. Students were given a Green Chemistry sustainability test in a pre-post design. Students participated in a semi-structured interview as well. Data analysis (t-test, content analysis) indicated that there was a significant difference in favour of the PBL experimental group in the post-test scores. Students reported that the problem scenario from daily life enhanced their interest and played a positive role to enhance students' level of environmental awareness and understanding of sustainability and green chemistry.

Reinforcing the need for intrinsic motivation, a study by Gurses et al., 2007 with pre-post research design suggests that learning through the PBL approach is purposeful and self-motivating. This study with forty 3rd-year undergraduates was carried out for the physical chemistry laboratory involving four experiments (adsorption, viscosity, surface tension, and conductivity). They describe that the problem should be complex enough that compels students to cooperate with one another and collectively assume responsibility for their learning and instruction. This study demonstrates that PBL promoted active participation through the identification of own learning needs.

In another study on students' perception of PBL, Mataka, 2014 explored the attitude and self-efficacy beliefs in her dissertation work. The convergent mixed methods research (quantitative and qualitative research approach) utilized PBL environment inventory (PBLEI) and interviews. The quantitative factor analysis, t-test, and ANOVA helped her to conclude that there is a positive correlation between PBL and students' self-efficacy beliefs. Furthermore, PBL has the potential to improve students' attitudes towards chemistry and self-efficacy. In a similar attempt to understand students' attitudes, Kelly and Finlayson, 2007 tried to evaluate students' experience of a PBL module through both qualitative and quantitative data. They inferred that the learning and enjoyment were better than the traditional laboratory with 83% students showing a preference for the PBL approach. Thus, the PBL approach is seen as a success by these researchers. Kelly and Finlayson's results indicated that a small number of students commented on the difficulties with individual group members but by and large their findings were opposed to the one by Seng Tan, 2004 who contended that group work is a negative aspect of the PBL.

2.5 Summary

The undergraduate chemistry laboratory goals suggested in the literature can be categorized into cognitive, affective, and psychomotor domains. While it is necessary for students to learn *how to do chemistry*, the lab curriculum should be aligned with the goals of students and teachers for meaningful learning. With an understanding that pros and cons are a part of all instructional styles, PBL approach was chosen as an alternative instructional style for further exploration.

Literature suggests that PBL in chemistry laboratories has been studied extensively and the results are encouraging both in terms of meeting the cognitive and affective goals of the laboratory. Successful PBL needs students to take ownership of their learning and the group work seems to be providing the necessary support for students to navigate through the problem. Some studies have mentioned the formation of a group for the work is challenging. However, the authors also acknowledge that this difficulty is not unique to PBL or is inherent to this approach.

The literature also indicates that several PBL module has been developed across domains of chemistry. PBL also fosters the science practice skills of formulating hypotheses, designing experiments, and collecting data to provide a solution to the stated problem. Thus, PBL seems to be one of the good alternatives to expository laboratory styles. Before planning a PBL module considering the local requirement, it is important to understand the present status of undergraduate chemistry laboratories in the Indian context which is presented in the next chapter.

Chapter 3

Chemistry lab education: The Indian context

3.1 Overview of the chapter

This chapter presents an overview of the nature of chemistry lab education in the region where this study was conducted. The details of the analysis of representative lab manuals are presented here. Additionally, the views on lab education by two of the authors of the lab manuals are narrated here. Further, a survey was conducted to understand the perception of students and teachers regarding their preferred goals of undergraduate chemistry laboratory education. Based on the results of the survey, an inquiry module was designed and implemented with undergraduate students to understand the feasibility of implementing an inquiry module. This chapter describes all these aspects which constructed the background knowledge required to plan the main study on PBL.

3.1.1 CER literature on lab manuals analysis

It is useful to understand the way CER researchers have carried out the analysis of lab manuals before analyzing the Indian lab manuals. The following section presents a few seminal works carried out by researchers to understand the expected learning outcome through the analysis of the chemistry laboratory manuals.

Domin, 1999b conducted a detailed content analysis of 10 undergraduate chemistry laboratory manuals by considering three experiments (involving gas laws, kinetics, and colourimetry). He used the list of illustrative verbs prepared by Gronlund, 1985 as the framework for this analysis. He divided the levels of Bloom's taxonomy into two categories, lower-order cognitive skills, and higher-order cognitive skills. The study concluded that a large number, that is, 8 out of 10 manuals require the learner to operate at the lower levels of Bloom's cognitive taxonomy. The outcome of the study by Domin, 1999b indicated that the instruction is mostly falling under lower-order skills.

Buck et al., 2008 analyzed 22 manuals of physics, chemistry, and biology to understand the level of inquiry of 400 experiments included in them. Table 3.1 provides the number of experiments in different levels. The table also indicates how the levels can be identified.

Table 3.1: Inquiry levels (Bruck et al., 2008)

Description	Level-0	Level-1/2	Level-1	Level-2	Level-3
229 experiments in 13 chemistry lab manuals	12	191	21	5	0
	Confirmatory	Structured inquiry	Guided inquiry	Open inquiry	Authentic inquiry
Problem / question / aim	Provided	Provided	Provided	Provided	Not Provided
Theory / Background	Provided	Provided	Provided	Provided	Not Provided
Procedure/Design	Provided	Provided	Provided	Not Provided	Not Provided
Result and Analysis	Provided	Provided	Not Provided	Not Provided	Not Provided
Result communication	Provided	Not Provided	Not Provided	Not Provided	Not Provided
Conclusion	Provided	Not Provided	Not Provided	Not Provided	Not Provided

The levels are classified based on the quantum of information provided to the students as indicated in Table 3.1. This analysis concluded that in the vast majority of experiments, 386 (out of 400 included in physics, chemistry and biology manuals) followed inquiry level-0 or level-1/2. Of the 229 experiments in the chemistry laboratory manuals, most of the experiments (191) fall under inquiry level 1/2. The lab manuals which present lower-order cognitive engagement are intended, possibly, to reduce the time needed for the completion of a laboratory activity without navigating the students toward experimentation/investigation. Such lab manuals are used for teaching majority of students.

Bopegedera, 2011 suggests that instead of choosing a lab manual that is readily available in the market, a lab write-up should be prepared for each lab to engage students at higher cognitive levels.

Since there is sparse work related to the thematic content analysis of lab manuals, the themes for analysis were devised and the analysis of lab manuals based on these themes is presented in the next section.

3.1.2 Analysis of the lab manuals

General outline of the manuals

Chemistry lab manuals from Mumbai University(MU) and Savitribai Phule University(SPPU) were analyzed in detail. A total of six manuals for all three years of the undergraduate program from both of these universities were analysed. The syllabus in these manuals is followed in approximately 1500 colleges affiliated with these universities.

Multiple publishers publish lab manuals written by different authors who follow the curriculum developed by universities. The latest edition of the lab manuals published by Manali publications prescribed by SPPU and Himalaya publication by Mumbai were procured. These manuals are also used in the colleges where the trials for the research study were carried out.

The preface, index, and experimental procedure in the manuals were used for the content analysis. The sequence of the lab manuals typically starts with the syllabus followed by the contents table, the experiments of different domains and their procedure in the sequence

of physical, inorganic, and organic chemistry. Questions related to the concepts in the experiment are given at the end.
The following themes were used as thematic analysis and is described in the next section.

- learning objectives,
- core chemistry concepts,
- lab and instrumental techniques,
- real-life context,
- green chemistry experiments,
- levels of inquiry,
- interesting feature, if any.

3.1.3 Learning objectives in the manuals

The manuals were analyzed to understand the mentioned learning objectives. The preface of the MU manual starts by saying that *"the objectives are the same as before"*. The context of this statement is unclear and the previous edition was not accessible, making it difficult to connect. It is important to mention the objective as it draws both the learner's and the instructor's attention to what students need to learn. Regarding the concepts to be learned, the preface of the first-year lab manual of MU suggests, *"the alternatives can be introduced only after the basic concepts are known to the students"* without elaborating on what kind of alternatives the authors have in mind. The alternatives could be for chemicals, procedures, or the instructional approach.
The preface of SPPU manual states that it includes prelab questions in the manual that would be helpful to prepare the student for exams. Prelab questions are supposed to prepare students for conceptual understanding related to the conduct of the experiment.

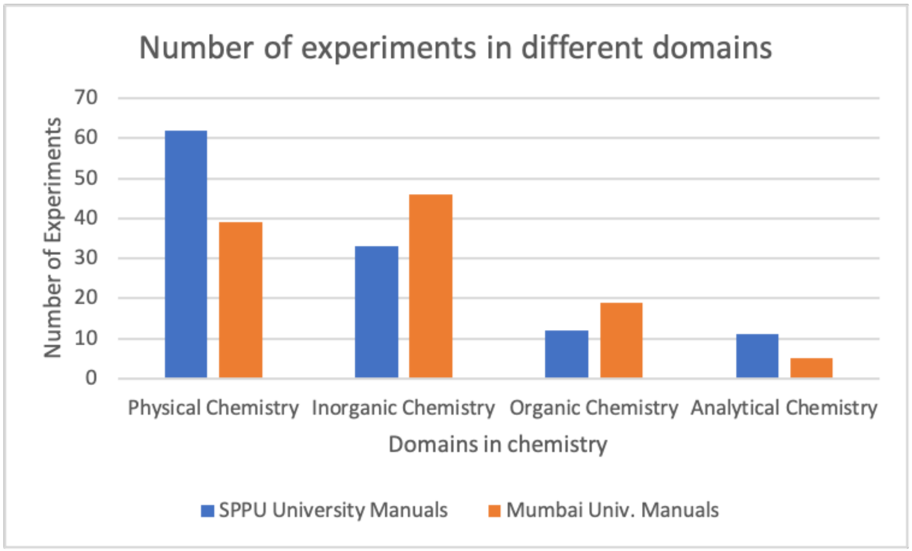
Since they are given towards the end of the manual and meant for exams, they cannot be considered as prelab questions. This idea of utilizing theoretical questions for evaluation is against what Hodson, 2005 contends. He suggests that laboratory education should assess the laboratory or the investigatory skills and not on the theoretical/conceptual questions. *The book will be useful for developing skills in various lab techniques*, states the preface. Hands-on practice is what can be expected to lead to such expertise though the preface does not state it.

Further, the aspects that are stated as the highlights of the manual are, a) simple language, b) a systematic theoretical background, c) mention of chemicals and apparatus needed for the experiment, and d) the stepwise procedure of the experiment. This suggests that the manual supports conventional laboratory education. Further, the preface of the manuals from both universities mentions that the contents will prepare students for viva voce exams and guide them to write the journal.

3.1.4 Core concepts/techniques in the manual

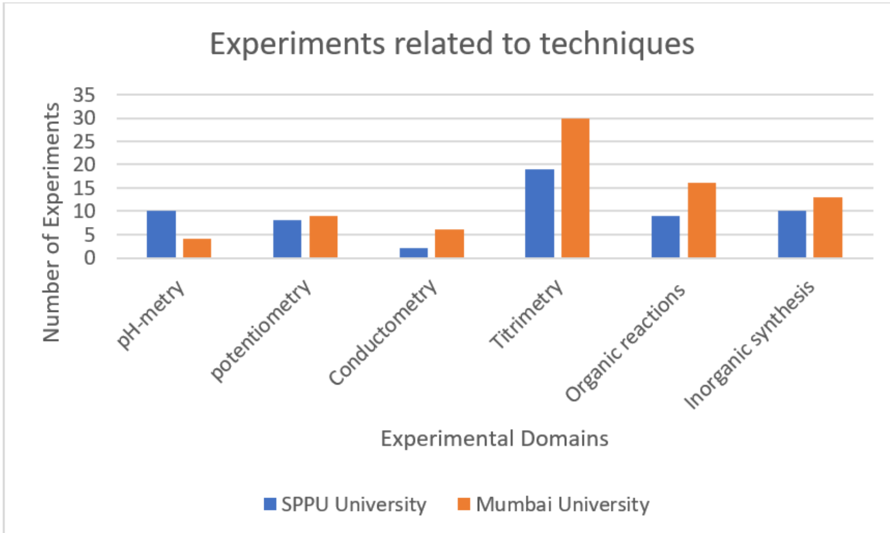
The total number of experiments for all three years is more or less similar in the syllabus of the two universities (118 for SPPU and 109 for MU) and is depicted in Figure 3.1.

Figure 3.1: Number of experiments in different domain



The SPPU syllabus gives more physical chemistry experiments whereas the MU syllabus gives more inorganic/organic experiments. The predominant concepts and techniques in physical chemistry are thermochemistry, kinetics, potentiometry, and pH-metry. There are a few experiments related to concepts such as adsorption, solution (colligative properties), and radioactivity in the SPPU manual and none in the MU manual. However, the number of experiments involving instrumentation techniques is less in both manuals. Figure 3.2 details experiments with various techniques.

Figure 3.2: Experiments related to techniques



The graph indicates titration as the most predominant technique across physical, organic, and inorganic (MU-30 experiments; SPPU-19 experiments). The reasons could be, a) ease of performance, b) low cost of equipment, c) proven/standardized procedural methods for quantitative estimation, d) physical, inorganic, and organic experiments could be performed by this technique. Further, the availability of standardized procedures makes titrimetry adaptable across all colleges even with less infrastructure.

The organic domain includes usual experiments such as a) qualitative analysis, b) quantitative analysis techniques, and c) preparation of compounds. Inorganic chemistry includes experiments such as semi-micro analysis and inorganic synthesis of coordination compounds. Organic reactions include the preparation of compounds or derivatives (preparation of derivatives involves confirmation of functional group) and synthesis (yield calculation).

Experiments belonging to analytical chemistry (techniques for the identification of structure and composition such as XRD) and qualitative techniques are also less in number.

The other important experiments are related to the inorganic synthesis of coordination compounds, qualitative analysis of inorganic salts, and analysis of organic compounds.

Experiments based on instrumental analysis are very few indicating the development of instrumental skills is not considered a priority in the undergraduate syllabus. Possibly, the availability of funds and the added cost of maintenance may be a factor for not including it as a priority. The unconventional areas such as nano-synthesis, radio-activity, and instrumental analytical techniques such as flame photometry, UV visible spectrophotometry, IR, and NMR have been included in the SPPU syllabus and none in the MU syllabus. In general, the experiments that are easy to perform and require less expensive equipment seem to be more in number in the syllabus of both universities.

3.1.5 Experiments based on real-life context

Context-based chemistry situates students' learning in a real-world scenario. In such an approach, the chemical concepts and their application are purposefully included to connect students with everyday life. It is found that students enjoy context-based chemistry curricula and realize the relevance of chemistry to their lives (Gutwill-Wise, 2001). The researchers have tried multiple topics such as cosmetics, the caloric value of chips, analysis of sunscreen lotion, etc.(Mc Donnell et al., 2007) to be included as context-based experiments. In India, UGC guidelines for the syllabus for the B.Sc. (Chemistry), suggest experiments such as analysis of Soaps and Detergents, Biofuels, Preparation of Nylon 6, vitamin C Synthesis, and testing of adulterants in food, oil and vegetables from everyday life. Out of the total 118 and 109 experiments, there are 24 and 18 experiments that are context based in SPPU and MU syllabi, respectively. But the context is presented with lesser elaboration to bring real-life utility. Research suggests that the use of context motivates and fosters positive attitudes to science without compromising learners' understanding of scientific ideas (Overton, 2016). It is thus important to include context wherever possible and there is a possibility to increase the number of context-based experiments in the curricula.

3.1.6 Green chemistry context

Sensitizing students to the green chemistry concept/approach is important for understanding the concept of sustainability. Such an approach should be integral to experiments. The SPPU manual explicitly mentions the green approach for some of the experiments whereas there is no mention of the green approach in the MU manual. The experiments that are specifically labelled as the green approach were counted and it was found that there are less than 1 per cent, and 0 experiments with the green approach in SPPU and MU syllabi, respectively. Some experiments such as, *Identification of Organic Compounds by Micro-scale Techniques*, can be included under the green approach, though the manual does not specify it. It is important to make serious efforts to sensitize students in this direction through chemistry lab education.

3.1.7 Levels of inquiry in the experiments

The description of the procedural write-ups of all experiments includes related theory/concepts, the list of chemicals and glassware, the step-wise procedure, ready-made tables to record observations, and finally, fill-in blanks for noting their results. Such a presentation is characteristic of a lab course conducted in the conventional style and provides less scope for cognitive engagement suggested also by Domin, 1999a.

This sort of instructional style follows the zeroth level of inquiry where the lab is highly structured (Buck et al., 2008). Additionally, the general framework suggests that the goal is towards developing lab skills and the chemical concepts associated with those experiments.

Thus, the outcome of this analysis is, the lab manuals, a) do not provide the objectives/goals, b) promote conventional laboratory education, c) have all experiments that follow level-0 (Table 3.1), d) provide procedures for the development of lab skills, and e) less number of context and green chemistry experiments. To corroborate the outcome of the analysis of the manuals, two of the authors of the manual prescribed by SPPU were interviewed. The following section presents a brief synthesis of the discussion. Of the two authors, one was a retired undergraduate female teacher with more than 25 years of experience and the other one, a male teacher, had 25 years of teaching experience including laboratory courses. The reliability of the interview data was established through member check.

3.1.8 Response of Author-1

The first authors suggested that the syllabus designed by the Board of Studies of the University is strictly followed by the affiliated colleges. The colleges have less freedom in choosing an instruction different from what is prescribed. The previous editions of the manuals are referred for publishing newer editions that do not significantly differ from the previous edition. The authors write the procedure of the experiments in their domain of expertise. If at all deemed necessary, a slight modification in the procedure is carried out based on the experience of conducting the lab, suggested the author. For example, in the potentiometric titration of phosphoric acid, this author proposed adding calcium chloride to get a sharp third inflexion point for the dissociation of acid. This discussion suggests that any change in experimental procedures is tried and tested before introducing in the manual.

3.1.9 Response of Author-2

The second author suggested that the curriculum is passed down by University Grants Commission (a central body governing the higher education landscape in India), to the Board of Studies (BOS). The BOS generally has people from different backgrounds such as experts from the industry and experienced teachers with diverse backgrounds. While designing the curriculum, they take into consideration a) the foundational concepts that students should learn, b) the relevance in the present-day context(for example, water analysis), and c) references from foreign universities.

The references mentioned in national and international publications such as the Journal of Chemical Education are chosen for writing the experimental procedure. However, the inquiry-based experiments are not a part of the current syllabus because the syllabus is followed in many colleges in urban and rural Maharashtra and the availability of resources cannot be guaranteed, suggested the author. This idea is in line with what was found in the analysis of the manual. Thus, it can be inferred that there is less flexibility in changing the syllabus as well as the experimental procedure written in the manuals. There may be resource constraints (material, finance, and competent instructor) in introducing inquiry or advanced instrumental techniques.

Responding to the question on why the manuals are not presenting the learning objectives, the author said that bringing the theoretical concept to practical understanding is the main objective of laboratory education. Perhaps the author did not see the need to state the learning objective explicitly.

Further, the change in the syllabus is carried out once in 5 years based on demand by the industrial experts. For example, water analysis, food analysis and pharmaceutical analysis are included in UG and PG levels in the recent past to comply with the recommendation of experts from the industry. Such experiments provide real-life context.

The autonomous colleges, where the availability of funds is not a constraint, include instrumental analytical techniques, said the author. This corroborates the analysis of lab manuals which indicated that there are optional instrumental analytical experiments included in the SPPU syllabus. He further added that the lab manuals provide ready-made procedures, and that the students need motivation. Context-based experiments and career prospects are important. The benefits for future career prospects, application in day-to-day life, and skill development are given as the reasons for doing lab experiments. The author's statement suggests that the inclusion of experiments situated in real-life contexts is important to motivate students and help them see the connection with their future careers, an aspect that is presented under the section on context-based experiments.

Answering the question on how the learning objectives are communicated to the students, the second author also suggested that even though the learning objectives are not mentioned in the lab manuals, the instructors generally explain the application of the experiment, and motivate students by suggesting how the lab education adds to skill development needed for the career later. The way experimental procedures are given in the manuals with well-laid out and highly structured content reflects the importance of developing lab skills.

Finally, the authors' suggestions can be substantiated by the learning outcome mentioned in the syllabus on the SPPU website ("F.Y.B.Sc. Chemistry Syllabus, University of Pune", 2019). The website mentions that the learning objective is to impart practical skills and learn the basic concepts behind the experiments. The syllabi also mention the learning outcomes of the experiments included for that semester, for example, the learning outcome for the first semester is mentioned as, a) Determination of thermochemical parameters and related concepts,b) Techniques of pH measurements, c) Preparation of buffer solutions, d) Elemental analysis of organic compounds (non-instrumental), and e) Chromatography Techniques for separation of constituents of mixtures. Thus, the lab manual analysis, the interview of the authors, and the learning objectives mentioned on the SPPU website point out the conceptual understanding and developing lab skills as important goals.

The literature on CER emphasizes the development of inquiry skills. The undergraduate curriculum/design of the manuals has left it out of the scope even though inquiry experiments that do not require expensive equipment can be designed and implemented. For example, in the complexometric titration of Ca, instead of using a solution of calcium carbonate, students can hypothesize whether a glass of milk consumed by them fulfils the daily need for calcium as recommended by the health ministry and then test their hypothesis. Such tweaking of the aim of the experiment would allow the students to attempt a context-based inquiry experiment and possibly remain motivated in the investigation.

Further, to understand what the students and teachers opine about the preferred learning goals of laboratory education, a survey was done with a group of 58 students and 37 teachers. The need for this survey is informed by the literature which suggests that the understanding of students' goals in the lab context may lead to better efficacy in developing the lab curricula (DeKorver and Towns, 2015). Further, the researchers also suggest that the possible gap between the recommended outcome and the actualization of the outcomes can be filled by aligning the laboratory curricular goals with the student's goals. Additionally, Hofstein and Lunetta, 1982 and Seery et al., 2019 posited that any mismatch between the goals of the instructor and students may thwart learning in the laboratory. Thus, an attempt was made to understand what the faculty and the students think as the preferred goals before designing the PBL module. The following section presents the survey data.

3.2 Perceived goals of laboratory education

A rank-order questionnaire (Appendix-B) was developed and piloted with a group of 4 teachers. There were six statements in the questionnaire related to collaborative learning, environmentally sustainable practices, chemical concepts, career prospects, problem-solving, and lab skills. The survey participants had to rank them from 1 to 6 (Rank-1 highest priority and rank-6 with the least priority).

Participants of the pilot study were interviewed to understand whether their interpretation of the lab goal statements was aligned with what was intended. Their suggestions were considered to modify the goal statements to bring better clarity in terms of the language.

Student participants

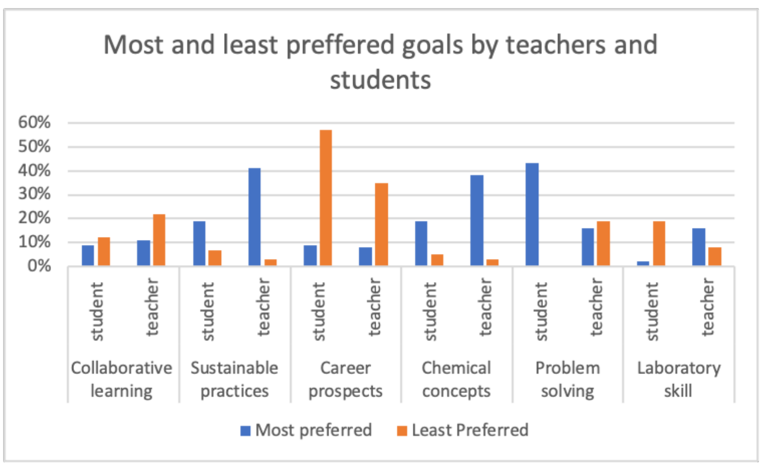
Fifty-eight first-year undergraduate students had completed one semester of a conventional lab course. These students were from all across India from different universities and were invited for a winter workshop through the announcement made on the HBCSE institute website. The students were given five days of exposure to the inquiry-based lab and then the survey questionnaire was given. This was important because, without having an understanding of what inquiry lab and problem-solving mean, expecting students to rank a statement on it would raise validity concerns.

Teacher participants

Thirty-eight undergraduate teachers teaching in the colleges affiliated with SPPU and MU consented to participate in the survey. Their experience levels ranged from a couple of years to 20-plus years. The teachers also were given exposure to an inquiry lab before giving them the questionnaire.

Informed written consent was taken from all the participants. The data was analyzed by counting the frequencies of rank-1 and rank-6 for various goal statements. If a particular goal statement received the largest number of rank-1, it was considered the most preferred statement. Likewise, if a goal statement received the largest number of rank-6, it was considered least preferred. Thus, the frequency of the rank-1 and rank-6 was counted against each goal statement and plotted to understand which statements are the most and least preferred ones. The results are presented in figure 3.3.

Figure 3.3: Most and least preferred goals by teachers and students



The statement on problem-solving was considered the most preferred goal by students. 43% of the students ranked it as first and none gave it a rank-6. The percentage goes up to 71% if the number of students who assigned this statement either a rank-1 or a rank-2 are combined. This was in contrast to teachers' choice. 41% of teachers chose environmentally sustainable practice as the most preferred goal and only 16% thought problem solving should be the most preferred goal. Contrasting the teacher's choice, only a small number of students (19%) assigned rank-1 to this goal statement on environmentally sustainable practice. Regarding the understanding of chemical concepts through lab work, 38% teachers and 19% students assigned it as the most preferred goal. This survey also indicated that both students and teachers give the least priority in assuming laboratory education would provide career prospects. This may stem from the fact that first-year undergraduate students have not decided on pursuing chemistry later in their careers. The least preferred career prospect is in contrast to what was suggested by the author as a motivating factor for the students to perform laboratory work.

This study suggests the need for designing experiments with a problem-solving approach and the problem itself could be designed to offer an inquiry experience, develop conceptual understading and be in line with the environmentally sustainable practices. This approach would help in aligning the goals of teachers, students, and the CER literature. Such alignment is considered of value by researchers such as DeKorver and Towns, 2015; Duis et al., 2013; Hofstein and Lunetta, 2004. In order to understand the challenges involved in implementing inquiry experiments in conventional laboratories, a feasibility study was conducted. The following section details the implementation of the vitamin C PBL module.

3.3 Implementation study of vitamin C module

Vitamin C estimation by pH-metry is a part of the existing MU syllabus. The experiment was modified and designed to comply with an inquiry level-2. The following section gives the rationale for choosing vitamin C for titrimetric estimation.

3.3.1 Rationale for choice of vitamin C for inquiry laboratory module

- Vitamin C provides a good real-life context. Most of the vegetables and fruits we eat contain vitamin C in varying amounts. Knowing the amount of vitamin C in supplements or other products to be consumed by human beings provides a good real-life context to students as is required in PBL.

- Both the natural samples like fruits or vegetables and market samples like juice powder or tablets have multiple constituents offering required challenges through predictable chemical interference in the analysis of vitamin C.
- The estimation of vitamin C can be carried out by acid-base and redox titrations. Within redox titrimetric methods, several choices are available such as dichloroindophenol (DCIP) titration, iodometry, and titration using ferric chloride. These titrimetric methods require chemicals and resources that are easily available and are less expensive making it feasible to implement in regular colleges.
- Depending on the availability of the instruments, colourimetry and spectrophotometry could also be carried out to introduce instrumentation to students.
- Estimation of two samples for vitamin C content by two methods allows students to collect enough data for analysis and interpretation. This helps to infer the suitability of available methods for the chosen sample. The deviation from the expected results may arise due to personal errors or inaccurate solutions which students have to be mindful of while drawing inferences from their data.
- There is a possibility to give students the freedom to try out more experiments with variables like sample mass, volume, or the type of sample.

In conventional laboratories, often, students work individually and algorithmically follow the procedure given in the manual to get the correct result. Such an instructional approach offers little challenge and opportunity to engage students in higher-order thinking skills e.g., critical thinking, decision-making, etc. Further, students need to understand laboratory techniques and develop troubleshooting skills. Since Problem-based learning provides an opportunity for such a learning experience through collaborative learning, it was decided to convert "Estimation of vitamin C" to a PBL module to make this experiment a cognitively stimulating task and for a wider learning experience.

Table 3.2 provides an understanding of the components that matches those characteristics. The characteristic of PBL described in the literature was mapped with the design of the present module. Table 3.3 distinguishes various aspects of traditional and PBL approaches.

Table 3.2: PBL characteristic of vitamin C- PBL module

S.No.	PBL characteristics	Component of vitamin C PBL- module
1.	Contextual problem	Comparison of titrimetric methods for estimation of vitamin C present in the market samples.
2.	Acquisition of new knowledge	Stoichiometric calculation for sample preparation, Procedure for titration with potassium iodate
3.	Data analysis	To predict the possible chemical interferences, to infer suitability of a method for the sample
4.	Concepts strengthened	Mole concept, law of equivalence

Table 3.3: Comparison of traditional and PBL module on the estimation of vitamin C

Description	Traditional method	Vitamin C - PBL module	Advantage in PBL format
Aim	given	given	students need to define it
Procedure	stepwise instruction	students to design the precise steps (mass, volume etc. to be taken)	helps develop design skills
Stoichiometric Calculations	given	calculations by students	strengthens concepts while engaging in calculations needed through the given problem
Equations related to titrations	given	to write the equations needed for use in stoichiometric calculations.	connect theory to practice
Data analysis	all steps given	involved interpretation of data	exposure to data analysis (skill transferrable to other domains)
Correctness of result	emphasis on final correct result	designed to understand errors and variation	can discuss on variation and errors (skill transferable to other domains)
Assessment	based on journal maintained	based on prelab, lab and post-lab work, worksheet, presentation and assignment	assessment in line with expected learning outcome

From the table, it can be inferred that the PBL approach gives a wider learning experience.

3.3.2 Design of the module

The key idea was, to draw students' attention to the components of the sample (other than vitamin C) that may interfere with the estimation. Thus, students either had to predict the interference apriori and/or reason them post-facto using the data.

The module (Appendix C) had pre-lab, lab, and post-lab components. The introduction section of the pre-lab task sheet presented the context of vitamin C and the chemical information needed to carry out the work. The information included basic chemical principles related to the estimation of vitamin C by a) redox titration using KIO_3, b) acid-base titration using NaOH, and c) redox titration using $FeCl_3$. However, the procedural details of these methods were avoided in contrast to the way it is given in laboratory manuals. Students were supposed to design the experiment by choosing the samples, the methods, the concentration, and the amount of the chemicals.

Students were provided with a lab task sheet with pointers and space for constructing an observation table for recording the titration readings and for calculations of vitamin C content. The post-lab task sheet contained space to record their interpretation, and difficulties faced. The objective of the task was to complete the following grid by pooling the classroom data (Table 3.4) and to present an appropriate rationale for the conclusion.

Table 3.4: Titrimetric estimation of vitamin C task outcome

Vitamin C Sample	Method-1 (Redox)	Method-2 (Acid-base)	Method-3 (Redox)
Sample-1	S*/NS**	S/NS	S/NS
Sample-2 (with one interfering component)	S/NS	S/NS	S/NS
Sample-3 (multiple interfering components)	S/NS	S/NS	S/NS

(S*:Suitable and NS**: Not suitable)

The expected learning objectives were, a) revisit concepts of molar calculations and apply them in the given context, b) plan the appropriate procedural details and execute the plan in the laboratory, c) collate and compare the class data, d) Arrive at data-based inference, and e) Engage with soft skills like teamwork and communication.

3.3.3 Structure of the module

The module had pre-lab, lab and posts-lab tasks. The introduction section presented the context of vitamin C and the chemical information needed to carry out the work. In Part-1 of pre-lab, students were asked to select two samples for analysis and to provide the rationale for the same. Part-2 of the pre-lab work provided basic principles for the estimation of vitamin C by three methods, using a) dichloroindophenol, DCIP method, b) iodometry using potassium iodate and acid-base titration using c) sodium hydroxide. The vitamin C samples were Limsee tablet, Celine tablet and Glucon-D. Limsee tablet has components (sodium ascorbate) that interfere with the acid-base titration while Glucon-D has components (sugars) that interfere with redox titrations. These vitamin C samples have chemically interfering substances which pushes them closer to real-life samples which are never pure and we can bring this awareness through the experimental work. Additionally, Glucon-D contains very little vitamin C which needs student's attention before making a choice of this sample to decide whether to choose it or not. Students need to hypothesise and then experimentally prove that these two methods are unsuitable for the respective samples. At the same time, they have to conclude at the end of the experiment that the titration using dichloroindophenol is the most suitable and Celine tablet is the best sample for the titrimetric method.

Even though Celine does not contain any chemical interference, it has components like binders. A small error in the results for this sample owes only to the binders. Students need to figure it out. The task is the identification of the best-suited method. This task provides a chance for the students to hypothesise, collect data, interpret and reason out the cause of errors.

The main objective was to understand the feasibility and challenges of implementation of this PBL module in a regular setting of a college. The following section describes the study on the implementation of a simple PBL module and its conclusions.

This section presents the experiences related to the implementation of an inquiry-based approach in a chemistry laboratory. The objectives of the study were to understand,

1. Feasibility of implementation of an inquiry-based (PBL) experimental module in an undergraduate chemistry laboratory,

2. Student's perception of the inquiry module.

3.3.4 Implementation of vitamin C module

The module was tried with two different groups of first-year undergraduate students. Study-1 (n=12) was carried out with a group of students who were invited for a winter workshop in our research institute (HBCSE, TIFR, Mumbai). These participants were students from different colleges across India. Study-2 was carried out with the students in their college in Mumbai (n=32).

Students carried out the task in small groups (3 students in each group) and the time allocated was four sessions of three hours each spread over two days. The researcher acted as the facilitator in both of these studies.

During the pre-lab session, students needed to discuss and choose any two vitamin C samples from the given three samples and two methods for titrimetric analysis from the given three methods. Students were expected to provide reason(s) for their choices. Then, students had to write the appropriate balanced chemical reactions, identify stoichiometry, and calculate the amount of the sample to be weighed for the preparation of the solution for the analysis. The constraint imposed was, that the titre value should fall between 10.0 to 15.0 mL. After providing enough time for this exercise (about one hour), the facilitator collectively discussed the calculations with the class to provide an opportunity for corrections, if any. The prelab tasks provided an opportunity for students to learn the prerequisites, in case they were not aware of the same.

In the laboratory, students prepared sample solutions as per their molar calculations and performed titrations by the methods chosen by them. The procedures for the titrations were generated by them either through discussion or there was a possibility that they would look up some online resource. However, the chemical concentrations, amount, volume, etc. had to be chosen through decision-making because of the imposed constraint of the titre value (which again could be chosen by the students from a range of 10 to 15 ml as mentioned earlier).

During post-lab work, they shared their results with different small groups to collate and reflect on the larger data. Collaborative learning was a part of the experience throughout.

3.3.5 The changes in the module after the first study

While conducting the trials in the laboratory, students faced the difficulties. Accordingly, some changes were made to the module. These include,

- Titration with ferric chloride was discarded for the second study as students found it difficult to maintain a temperature of 60 deg. during titration. Students of study-2 had to carry out acid-base and iodometric titrations.
- One of the vitamin C samples (orange glucon-D) was posing difficulty in the detection of the end-point due to the inherent orange colour of the sample. This sample was replaced by the white colour vitamin C sample (white glucon-D).
- During the first trial, students had to analyze two samples by two methods. The researcher found students were struggling to finish the lab work within the stipulated time and had to be given extra time. To understand whether the reduction in the number of samples helps students save time, the number of samples was reduced from two to one during our second study.
- Students did not have a reference sample for comparison and assumed errors to be personal. Thus, as a choice, a vitamin C sample (tablet) containing only ascorbic

acid was given as a reference sample during the second study.

The space provided for drawing the data table in the lab task sheet was not best utilized by students in study-1. The following changes were introduced in the lab task sheet for the students of study-2.

- The hydrogens in the chemical formula of vitamin C were marked 1 and 2 for the identification of carbon atoms undergoing deprotonation.
- A take-home assignment based on the molar calculation was given to help students recall the steps involved in the molar calculations.
- The observation table for recording the readings was introduced in the task sheet.
- A table for the compilation of results was introduced in the task sheet to help in the interpretation of the results. The final vitamin C task sheet is appended C.

3.3.6 Results and Discussions

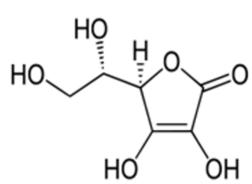
During pre-lab, writing balanced chemical equations for the titration reactions was challenging for students. Some students of study-1 could access the internet to write the correct balanced chemical equation. However, in study-2 the internet was not accessible to students and it was observed that students wrote multiple alternatives for the reactions (Table 3.5). They discussed the reactions they wrote, and accepted or rejected the alternatives, for example, they rejected reactions that could not be balanced or showed the evolution of O_2(which was not stated as a product in the information provided). Such discussion provides better learning opportunities than direct access to information from the internet. Table 3.5 indicates students' attempts to write molecular equations. Possibly a prompt in the task sheet may help draw students' attention to the entities involved in the redox half-reactions thereby possible mistakes could be avoided. However, it was easy for students to write the chemical equation between ascorbic acid and iodine because the molecular formula of dehydroascorbic acid was given in the introduction section of the prelab task sheet, suggesting stoichiometry.

Table 3.5: Chemical equations written by students

$KIO_3 + KI + HCl \longrightarrow I_2 + K_2O + O_2$
$KIO_3 + 5\,KI + 6\,HCl \longrightarrow 3\,I_2 + 6\,KCl + 3\,H_2O$
$3\,KIO_3 + 3\,KI + 3\,HCl \longrightarrow 3\,KOH\,3\,KCl + 3\,I_2 + 3\,O_2$
$KIO_3 + KI + HCl \longrightarrow KCl + KOH^{+}\,I_2 + H_2O$
$KIO_3 + K + 2\,HCl \longrightarrow KCl + H_2O + I_2 + O_2$

For an acid-base reaction, students had to ponder over the likely balanced chemical equation and the stoichiometry between sodium hydroxide and ascorbic acid. They were unsure of which hydrogen atom(s) (indicated by the numbers 1 and 2 in Figure 3.4) would be replaced. This dilemma provided an opportunity for discussion as arriving at the correct stoichiometry was important for deciding the amount of sample required for the preparation of the solution. Here students had to connect the theory with practice (titration). Thus, vitamin C poses an interesting titration problem.

Figure 3.4: Structure of ascorbic acid, vitamin C



1 **2**

The other difficulty was concerning calculations involving the mole concept. Students in both studies found molar calculations difficult.

The challenges were:

- correct use of molar ratio for determining the mass of ascorbic acid.
- using the following two equations together for finding the amount of vitamin C sample needed.

  Number of moles = MV   Number of moles = $\frac{W}{Molar Mass}$

  where, M- Molarity, V- Volume (in L), and W -weighed mass
- to consider the amount of vitamin C sample in the total stock solution rather than the volume needed for titration.

Often, as a part of the experimental procedure, students are provided with chemical equations and formulae for calculations. Instead, it is possible to provide opportunities to do these molar calculations on their own and reflect on the errors. This may help sustained learning for application in a newer situation.

Laboratory Work

During the prelab work, students did not notice chemically interfering substances present in the composition of the vitamin C sample. And, students performed the lab work with a lot of confidence because titration is a familiar task. When they encountered problems due to chemical interference, it was puzzling for them since they could not predict it. The puzzling result allowed students to ponder over what might have gone wrong. Day-1 was a little disappointing for the students, but a change in their outlook was noticed on day-2 in both studies. The puzzling result drew greater attention to the task. They became more careful and serious about the laboratory work; some students stated the same in their interviews/feedback. Many of them carried out the titrations again to ensure that the errors were not due to procedural negligence or personal errors.

For the given task, students had some freedom to extend the investigation. For instance, a group of students in study-2 tried to dissolve vitamin C tablets by heating, thinking that the solubility increases with temperature but their attempt was in vain. They did not consider the possibility of substances (binders) in the tablet that may be insoluble in water. Such instances were taken for discussion in the post-lab session and the interactions led students to reflect and realized that these substances may not interfere chemically but may affect the strength of the solution. Thus, titration of market samples of vitamin C gives exposure close to a true investigation.

Since students are in the phase of learning, facilitator cannot expect perfect laboratory skills and thus the facilitator needs to interact with them. A possible alternative is to show videos on titration techniques before they start the lab work.

Collation of the data

The post-lab task required students to collect and collate the data from all the students. The post-lab discussion session is, therefore, a vital component of collaborative learning because all groups do not try all the combinations. To facilitate the post-laboratory work as well, students were asked to construct the data table on the blackboard/whiteboard and each group entered the data collected by them during the lab work, which was followed by discussion.

The researcher observed that some students were uncomfortable accepting a flaw in the values obtained by them. The facilitator had to emphasize that the data belongs to all the groups for interpretation and students need to jointly and carefully accept/reject data points for holistic interpretation.

They concluded that acid-base and iodometry are suitable for the first sample which didn't contain any chemically interfering substances whereas iodometry is better for the second sample with sodium ascorbate as an interfering substance. Both the iodometry and acid-base titrations are not suitable for the third sample which had reducing agents.

Students' perception of the module

One of the objectives of this study was to capture students' impressions of this module. Students were asked about the strength and weaknesses of the module, as well as the interesting and boring parts of the module. Their perceptions about the collaborative work were also captured through a question in the feedback form (Appendix D). The following Table 3.6 provides a qualitative account of the results from 42 students from both studies.

Table 3.6: Qualitative account of students' responses in the feedback form

Descriptor	Typical Responses
Interaction with peers	We got the opportunity to know a) our mistakes b) other's opinions and ways of thinking c) problems faced by others and compare them with our own experiences d) new friends.
Strength of the module	We did not, a) blindly follow the instruction from the book b) put one value and calculate from the previously given data We got to, a) study the actual concept related to the experiment b) improved our skills and our thinking
Weakness of the module	It may be difficult if students, a) who did not know how to start the experiment b) are an introvert who would not speak up, then discussion may be difficult. c) think it lengthy or boring
Interesting part	a) deviation in the result of practical from theoretical values b) calculations (stated by 15 students) c) Experimental work (stated by 22 students) d) knowing our capability to solve the problem e) using familiar samples for estimation
Boring part	a) calculations (stated by16 students) b) Nothing (stated by 12 students)

These responses indicate that the students received support from their peers for understanding and completing the challenging task. The calculations were thought of as boring and interesting by an equal number of students. Further study may be required to understand the reason behind such opposing responses related to calculations.

Analysis of the lab task sheet indicates that about 21 out of 42 students chose to analyze glucon-D. Almost all of them reasoned that they would like to know about the energy drink used in day-to-day life. Most of them were curious to know about this sample, perhaps, because it offered a familiar context. This supports the design point that a context could motivate a student to learn.

Focus-group interviews with the students of study-1 indicated that students' experience with the module was quite unlike what they have come across in their college labs where they experience a spoon-fed model with no freedom/ownership in the work environment. Students thought that the most important learning was the opportunity to reflect on the errors. Some of them also stated that the actual learning took place while they were discussing collating the data for the presentation. These impressions suggest that we need to seriously rethink the current practice followed in experimental work in undergraduate colleges.

3.3.7 Challenges in implementation by a facilitator in a regular college

As stated earlier, in the conventional laboratory, students generally record only the titre value in a titrimetric experiment. It is important that the lab task sheets contain prompts that present cues to students to record various qualitative and quantitative observations. With such cues, students can start observing any noticeable change in the system that they work with. Introduction to pre-lab is important to prepare students for the task and the post-lab should focus on data evaluation for arriving at inference. It is equally important that students should not find the given task too frustrating as they are likely to be discouraged. It is essential to conduct a discussion with the entire class by posing questions that may act as a scaffold to help students to think and reflect. The instructors who need to take the role of facilitator, should not provide answers or give suggestive or directional cues. The facilitator needs to be careful to prevent digressions in discussion and navigate towards the desired outcomes. It is an ardent art needed by facilitators. Effective implementation of such inquiry modules is possible with appropriate orientation to teachers so that they take the role of facilitators.

3.3.8 Conclusion

Overall, the module on vitamin C in the present study provided multiple learning opportunities to students such as to — a) revisit concepts of molar calculations and apply them in the given context, b) plan the appropriate procedural details and execute the plan in the laboratory, c) collate and compare the class data, d) arrive at data-based inference, and e) engage with soft skills like teamwork and communication. The exploratory study helped to understand that there is a definite scope to introduce such approaches in laboratory settings of colleges in India. Further, class size in the laboratory work does not appear to be a constraint for implementation. It is important to implement such cognitively demanding activities as collaborative work. The additional advantage of group work is, it allows sharing of equipment during lab work. The module on vitamin C in the present study provided multiple learning opportunities to students such as given in Table 3.7.

Table 3.7: Multiple learning opportunities provided by the module on vitamin C.

Description	Learning objectives
Content Related	The presence of other components in the sample is an important factor when choosing an appropriate method of quantitative estimation of the main component (vitamin C)
Process Related	To design experiment To apply prior knowledge in a new situation
Procedure Related	To acquire laboratory skills related to titrations

Students completed the task despite the challenges faced which offered learning opportunities. The feedback from students suggested that they enjoyed the task and they appreciated the freedom given to them to choose samples and methods.

The module is structured based on the belief that the shift to an inquiry-based laboratory approach needs to be gradual for students from a conventional laboratory setup. The results of this study are in agreement with the results of the study by Scott and Pentecost, 2013 which indicated that the integration of a moderate level of inquiry increases the difficulty level of the task for the students. Thus, the transition to higher levels of inquiry may be feasible in an incremental manner i.e., a stepwise transition from structured inquiry to guided inquiry followed by open inquiry may be a better approach to introduce higher levels of inquiry.

3.4 Summary

The analysis of manuals helped to understand that the conventional style is followed by and large in colleges affiliated with MU and SPPU. The students and teachers prefer problem-solving and environmentally sustainable practices as the goals of the chemistry laboratory. Further, the feasibility study for implementing inquiry in the authentic setting of a local college provided encouraging results. Even though the inquiry task was well received by the students, the study indicated the need for scaffolds as tools to help students achieve the expected learning outcome. The results from the data of this chapter were encouraging to move forward with the design of a problem-based learning module integrated with necessary scaffolds. Before the design of PBL, it was essential to understand the conceptual and theoretical underpinnings of PBL as an instructional style which is presented in the next chapter.

Chapter 4

Conceptual and theoretical underpinnings of PBL

4.1 Overview of the chapter

Chapters 2 and 3 presented ideas that helped in developing a rationale for choosing an incremental approach to inquiry as an alternative mode of instruction for the lab module design. The short course has the first two modules with inquiry-based instruction and the next two modules have problem-based learning (PBL). The present chapter details the conceptual understanding of inquiry instructional style in general and PBL in specific. The core concepts of PBL such as the goals of PBL instruction, nature of the problem, and role of students, and facilitator in a PBL approach are described in this chapter. Further, the chapter also enumerates various theories and models in support of PBL as described in the literature. In addition, the factors that lead to failure and success of PBL are also presented in this chapter.

4.2 Inquiry Instruction

Inquiry instruction follows the active learning pedagogy which requires students to engage in self-directed learning.This constructivist approach is student-centric and the teacher vacillates between expert, guide, and facilitator when students take up the responsibility for their learning of the process and content as well. Inquiry-based instruction requires students' intrinsic motivation and a level of self-directedness and hence falls well under the constructivist framework. In such constructivist environment, learners build on prior knowledge, reflect and present their knowledge and, think critically and independently in small groups. Knowledge is typically constructed via interaction with the environment, and the meaning constructed by the learner is a unique process known to the learner alone. Constructivism states that culture, community and context influence thinking and meaning.

Inquiry-based learning (IBL) begins with a question/hypothesis followed by investigations to arrive at an answer and thus, closely follows the steps of scientific methods. It is considered a model in the teaching-learning process of science.

Based on the cognitive load many authors have raised concerns about inquiry instructional style in general, while converse of this has also been suggested by other researchers who provided evidence for better student engagement and retention using inquiry instructional style (Hood Cattaneo, 2017).

Inquiry-based and problem-based learning are a little different from each other in terms of whether the style is driven by a question or a problem. IBL is described by the levels of inquiry (described in detail in Chapter-3 Table 3.1). The following sections describe PBL in more detail.

4.3 Core features of PBL

PBL found its place in the medical curriculum in the 1970s when it was noticed that students were unable to apply discipline-specific knowledge (anatomy, neurology, pharmacology, etc.) to clinical cases. It was realized that the lecture approach did little to help them see the connection between theory and practice. Therefore, the need for new pedagogical means was realized and the PBL approach was initiated.

The core features of PBL described in the following sections are, a) PBL and its goal, b) PBL pedagogy (role of problem, facilitator, and student). The PBL expert authors whose seminal work have been collated below are, Baden and Major, 2004; Boud and Feletti, 2013; Hmelo-Silver, 2004; Overton et al., 2009; Schmidt, 1993.

4.3.1 What is PBL?

The early versions of PBL in the medical field have prescriptive features. For example, Barrows, 1996 stated that the key characteristic essential for PBL is a complex real-world situation that has no one right answer. Flynn and Biggs, 2012 claim in their work that the path to the solution is not always evident and there is often more than one way to the solution. Students are expected to work in teams to tackle the problem, identify learning gaps, and find a viable solution.

Boud and Feletti, 2013 define PBL as an approach to structuring a curriculum that involves challenging students with problems from practice that provide a stimulus for learning. They also state that PBL can be implemented in multiple ways.

According to Baden and Major, 2004, PBL is an approach to learning which helps to, a) develop reasoning skills, b) enable learning within a relevant context, c) ensure the learning is attuned to the world of work and, d) enhance self-directed learning abilities.

The PBL approach provides only the problem and partial information. Some of the information needed to solve the problem is withheld. The resulting knowledge gap becomes a learning issue for the students who explore resources to make progress (Lu et al., 2014). Collaborative learning helps students with the Vygotskian zone of optimal development (where a skilled peer can influence the learning of the student who cannot accomplish it individually). Because of collaborative learning and purposeful dialogue, students' learning generally exceeds what is otherwise possible or expected under a traditional approach (Baden and Major, 2004).

PBL emphasizes the use of propositional knowledge to be effectively used in a new situation. Hence, it does not reject the need for content knowledge but denies the way the content is learned through rote learning. The focus of the approach thus centres on helping students to utilize their previous knowledge and ways of thinking to construct a meaningful and understandable form of newer knowledge (Boud and Feletti, 2013).

In this student-centred approach, Kelly and Finlayson, 2007 contend that the problem challenges learners to take responsibility for their learning and progress, and thus the aim is to develop self-directed, reflective, and lifelong learners. Additionally, the learners emerge with skills such as critical thinking and soft skills that are desirable in the workplace.

PBL is a subcategory of context-based learning in which the problem scenarios themselves provide context. The problems act as the drivers for new learning (Overton et al., 2009) i.e. the problem is provided before the relevant learning is expected to take place. Further, the authors support the view that learning in PBL relies on building on prior knowledge and engaging in problem-solving involving reflections and critical thinking.

Proposing an explanation for the development of critical thinking skills, Lu et al., 2014 contend that the nature of the problem is ill-structured and complex which pushes the students to share their knowledge, search for newer information and negotiate alternative ideas to make progress in the collaborative learning process.

More importantly, students need to support their proposals and ideas through argumentation. This approach leads to the development of skills in reasoning, self-directed learning, and more coherent understanding (Hmelo-Silver, 2004). She further suggests that the PBL is a part of meaningful and experiential learning wherein students learn by solving the problem and reflecting on their experience.

Regarding the affective domain, Flynn and Biggs, 2012 claim that the real-life problem used in their study motivated the students. Further, learning in small groups leads to finding and evaluating appropriate resources, communicating effectively, and working independently of the instructor.

Goals of PBL

Hmelo-Silver, 2004 suggests the following as the goals of PBL,

"Helping students to develop, a) flexible knowledge (that can be restructured for application in a newer situation), b) effective problem solving, c) self-directed learning skills, d) item Effective collaborative skills and e) intrinsic motivation" Boud et al., 2013 included the following additional points that relate to the affective domain. *"a) Generating the desire and ability to think deeply and holistically, b) generating enthusiasm for learning from and utilizing all life's experiences in personal, professional and community development, c) encouraging the search beyond one's preconceptions, so becoming ultimately innovative and critical with self-respect and one's profession".*

To summarize, PBL involves engaging students with problem-solving wherein the problem is framed from a real-life/familiar context. During this exercise, students' prior knowledge is expected to get strengthened through its application in a new/unfamiliar situation and they acquire new knowledge through self-directed learning. Students collaboratively reflect on what they have learned and engage in argumentation and reasoning on the strategies for its effectiveness. The problem provides the requisite challenge to fill the knowledge gap facilitating knowledge construction. The student-centric approach develops critical thinking skills and motivates students to solve as per their ideas without forcing them toward a pre-determined outcome.

The task provided in PBL also helps students to acquire more general skills like critical thinking, communication, time management, planning, and work distribution. All these skills extend beyond any specific domain.

The teacher assumes the role of a facilitator and guides students optimally. The focus is not to impart problem-solving ability but to use the problem as a vehicle for learning concepts related to chemistry and experimentation. Good PBL modules provide opportunities to understand the problem scenarios holistically i.e., with their linkages to the relevant interconnected components within and beyond the scope of the problem. Such exposure may help learners develop a Systems Thinking Approach and encourage formulating a more meaningful solution to global problems (Nagarajan and Overton, 2019). Thus, PBL is often perceived by students as more useful (George-Williams et al., 2020) and has been successfully implemented across different areas of chemistry such as environmental, medicinal, analytical, organic chemistry etc.(Costantino and Barlocco, 2019; Flynn and Biggs, 2012; Hicks and Bevsek, 2012; Mc Donnell et al., 2007; Ram, 1999).

Three aspects of PBL instructional styles that are important to understand for a successful implementation are 1) the problem, 2) the role of facilitator, and 3) the role of students. The following section describes these aspects in detail.

4.3.2 Role of the problem

One of the important considerations in designing an ill-structured and complex problem is to make it realistic enough and resonate it with students' experiences so that the problems support students' intrinsic motivation (Overton et al., 2009). Contrasting structured problem solving, solutions to ill-structured problems require students to define the problem, identify the steps and make a choice from one of the many possible solutions. The problems should be challenging but not frustrating. In addition, the problems should provide scope for student engagement with argumentation and reasoning to evaluate the effectiveness of their learning process as compared to their initial understanding (Baden and Major, 2004).

H. Schmidt and Moust, 2010 categorized the problems based on the type of knowledge imparted. Table 4.1 connects the problems in PBL to the type of knowledge learned.

Table 4.1: Types of knowledge and problem

Type of Knowledge	Type of Problems
Explanatory Knowledge	Explanation problems
Descriptive knowledge	Fact-finding problems
Procedural knowledge	Strategy problems
Personal knowledge	Moral dilemma problems

They further add that, if students are explained the connection between types of knowledge and nature of the problem, they learn to recognize the epistemology of knowledge construction.

The problems could also be classified based on the nature of the tasks. For example, strategy tasks, action tasks, discussion tasks, study tasks, and explanation tasks are the problems suggested by Baden and Major, 2004. Kelly and Finlayson, 2007 suggest another way of categorizing problems and that is based on whether they are concept-driven problems (for example, molar calculations), skill development problems (technical, observation, data handling), and problems that need application of the understanding (for example, whether baking soda is effective at relieving indigestion and compare it with antacid tablets). The problem, once designed, can be presented to the students in different ways. Boud and Feletti, 2013 suggest that a problem could be presented in the form of an event, a descriptive statement, or a set of questions. Additionally, the authors also suggest that a problem should cover a predefined area of knowledge to help students learn a set of important concepts, ideas, and techniques, or typically represents a problem faced in a profession.

On the other hand, Baden and Major, 2004 suggests the following ways of writing and presenting the problem.

- *"Start with a problem about which students will have some knowledge, this develops their enthusiasm.*
- *Use problems that will gain their interest, such as those relevant to practice.*
- *The problem should have a puzzle, mystery, or some drama so that it is unclear at the start what is going on.*
- *Ensure that the probes are varied by using video clips, actors, answer machine messages, and different types of media presentations and not just paper cases. Students belong to the soundbite generation and thus the presentation of the material needs to*

reflect this.

- *Whenever possible use authentic problems and situations from real life. Students quickly pick out situations that are not authentic and consequently they feel that they are being manipulated into learning rather than stimulated to explore their own agendas.*"

Even though a lot has been said about the way problems should be designed, the starting point should be focused on students' capabilities, the skills they need to develop and the planned learning objective. Additionally, there must be a balance between the process and content to help students learn both these aspects of the PBL.

4.3.3 Role of facilitator

The role of the facilitator is critical in helping students in their effort to solve the given problem in PBL. In PBL, the teacher as facilitator provides guiding questions to initiate discussion and help students to articulate, thereby engaging students in active learning. Structuring the task, guiding questions that encourage reflective discussion, etc. are important scaffolds provided by the facilitator (Lu et al., 2014). Apart from these, the facilitator needs to monitor the group dynamics and ensure that the students learn to collaborate well. Though managing and facilitating many small groups may be challenging, the facilitator must ensure that all students are involved and contribute. The facilitator is expected to elicit explanations/reasoning, prevent digression during the discussion from the primary purpose and navigate students to the desired goal. The facilitation process is important for successful implementation of the PBL. The facilitator should nudge students to think deeply. Thus, expertise in facilitation is of utmost importance in staging the PBL process successfully.

In case of PBL lab work, the facilitator has the additional role of helping students through the difficulties encountered while performing the lab work. Since there is no direct instruction available to students, the facilitator can provide video links for carrying out the experimental procedure. Intermittent discussions could be carried out to clarify students' doubts related to the experimental setup. Beyond all these, the safety aspects cannot be compromised and the facilitator must be extremely watchful of any violation of the safety rules in the laboratory as PBL allows students' exploration of multiple solutions to a problem.

4.3.4 Role of students

The students have a very different role in a PBL instructional style as compared to the traditional approaches. Table 4.2 presents this difference.

Table 4.2: Traditional laboratory verses PBL laboratory

Traditional laboratory	PBL laboratory
The passive listener follows the stepwise procedure and instructions	Active participant, the problem solver, generates his/her experimental design
Aims to arrive at the correct answer to verify the concept of the experiment	Aims to verify the hypothesis through the interpretation of data
Participation is not influenced by the group members	Participation is motivated, monitored, and supported by group members
Work individually with peers in completing the task	Collaborates with peers to solve the problem
Learns independently through the provided material /lecture/demonstration	Self-directed and collaborative construction of knowledge

The students in PBL take ownership of problem-solving. They must also assume the role of a decision-maker in deciding the resource, strategies, and distribution of work or assume the responsibility of performing the task. The class is divided into small groups and one of the members of the small group assumes the role of a leader in assigning tasks to other members and communicating with the instructor and other small groups.

Students in PBL typically engage in group discussion for shared knowledge construction with the help of the facilitator, leading to engagement in problem-solving and higher-order thinking skills. The group discussion leads to the enrichment of cognitive structures as the prior knowledge gets tuned to the specific context through epistemic curiosity (Schmidt, 1993).

One of the important advantages of such collaboration among the student member is that the students do not continue with a knowledge gap as the knowledge is co-constructed. Thus, the role of students shifts majorly from being passive knowledge consumers in the traditional approach to active engagement in taking ownership of their learning.

4.4 PBL and Learning theories

PBL learning is an integrated approach to learning, drawing on several learning theories such as Humanistic theory, Constructivism, Situated Learning, Experiential Learning theory etc. (Kemp, 2011; Baden and Major, 2004).
Schmidt, 1993 claims that the PBL approach is strongly influenced by cognitive psychology with the roots in Dewey's recommendation to foster independent learning. The following section describes some of these theories in brief as the framework for PBL.

4.4.1 Humanist theory

The humanist theory contends that significant learning happens through situations that are both defined by and under the control of the learner. This theory acknowledges the need for prior knowledge and recognizes that students may be constrained by their own negative experiences of learning. As per the humanist theory, in PBL, the facilitator helps to provide a supportive environment for active learning wherein learners explore their needs. Being student-centred, PBL involves focusing on the starting point that each learner brings to the PBL process (Baden and Major, 2004)

4.4.2 Situated learning theory

As per situated cognition, the way learners make meanings, in a given context of knowledge construction, depends on the relationship between the learner, the situation and the interactions between the two. In a PBL, the situation or the meaningful context is provided by the ill-structured problems that the learners are solving. According to Marra et al., 2014, the knowledge that is anchored, or situated in specific contexts is more meaningful, more integrated, better retained and more transferrable.

4.4.3 Constructivism

When the learner is actively engaged in the environment, learning may happen at two levels. First, when they interact with the environment at the individual level (Piagetian constructivism) and the other when they engage in social interaction for the construction of knowledge (Vygotskian constructivism). Social engagement also has the advantage of allowing learners to test their knowledge leading them towards meta-cognitive awareness. In PBL, a hybrid approach is facilitated where students must engage in social discourse to gather and validate information as well as construct their knowledge individually (Kemp, 2011). Further, the learning is anchored by a meaningful context.

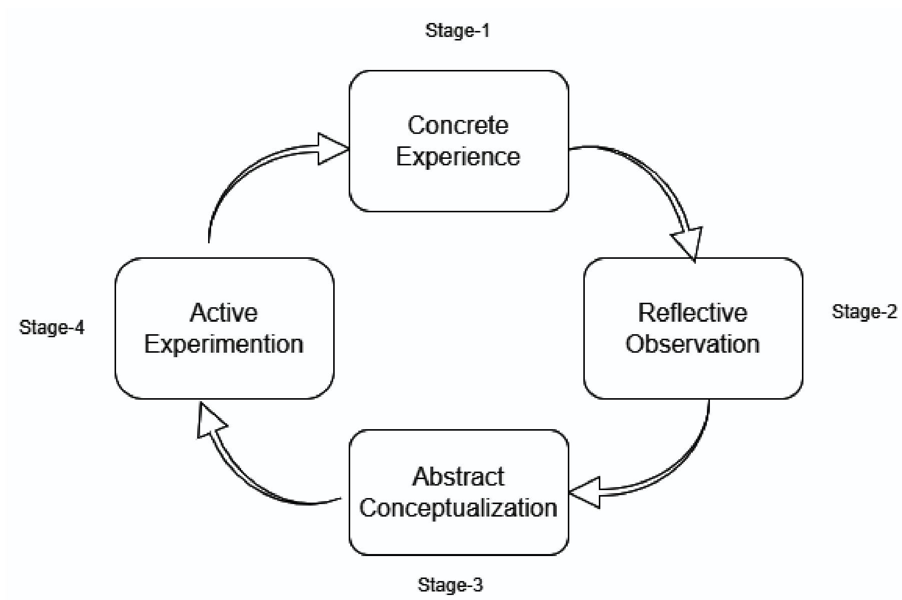
4.4.4 Experiential learning

PBL for laboratory work resorts to integrating concrete experience with abstract conceptualization. Concrete experiences are the basis for observation and reflection, and the laboratory is a space for experimentation and experience. Hence a close connection with PBL learning is found in the pragmatic work of Dewey who emphasized that reflection on experience is necessary to solve the problem and make meaning out of it (Kolb and Kolb, 2005; Miettinen, 2000).

According to Kolb's learning theory, the learner proceeds through four stages for effective learning (Kolb, 1984). These stages are— Concrete Experience (CE), Reflective Observation (RO), Abstract Conceptualization (AC), and Active Experimentation (AE). The CE stage includes the active engagement of students with a concept. The RO stage helps students review the experience and may include giving and receiving feedback from their peers. The AC stage helps students interpret events and generate models of what is experienced.

Finally, the AE stage involves students putting their learning into practice (Konak et al., 2014). All these stages constitute the Experiential Learning Cycle (ELC). Kolb's theory finds its intellectual origin in the learning models of Dewey, Piaget, and Lewin, giving an integrative perspective on experience, perception, cognition, and behaviour (Miettinen, 2000).

Figure 4.1: Kolb's ELC



In the context of the PBL chemistry laboratory, the first three stages of Kolb's theory (CE, RO, and AC stages) can be experienced by students during pre-lab work to generate conceptual and procedural understanding followed by the laboratory work that can be aligned with the fourth stage of AE. One of the important aspects of learning is engagement with reflective thinking on the information that the learner comes across. Reflective thinking is important for sense-making and critical thinking. However, reflective thinking can happen when a) there is a concrete interaction of the learner with the learning material as precedence, and b) by making the thinking visible to their peers and facilitators. The role of peers is very crucial in the reflective learning process because it leads to collaborative knowledge building. With peers, the learner can engage in a discussion and can seek clarification/explanation. Agreement and disagreement leading to argumentation and construction of explanation strongly favour learning in a social environment. The collaborative learning space provides an environment that supports this social activity and enhances individual learning. The collaboration makes students' thinking visible and hence provides an opportunity for metacognitive engagement. Thus, the theories by Kolb and Social Constructivism can be merged to explain the reflective co-construction of knowledge in a PBL environment.

Meaningful learning should happen at three levels namely, cognitive (e.g., brainstorming), affective (e.g., enjoying the process with peers, motivational), and psychomotor (experimentation, model making). An integrative perspective of theories facilitates learning. For example, the cognitive theory and experiential theory explain learning at the cognitive level, the humanist theory supports the affective domain, and the collaborative work in the laboratory related to the psychomotor domain can be explained by the social constructivist theory. Kolb's theory provides an opportunity to meet these three lab goals.

Table 4.3: Theories of Learning supporting PBL.

Theory	Aspects of PBL supported by theory
Humanist theory	Prior knowledge
Situated learning theory	Familiar context
Constructivism	Collaborative learning
Experiential learning	Reflection and conceptualisation for concrete experience

The focus of the present work is inclined more towards Kolb's theory of experiential learning. Especially for a scaffolded PBL lab, Kolb's theory provides a way to sequence the scaffolds (explained in detail in Chapter 5 Section 5.7).

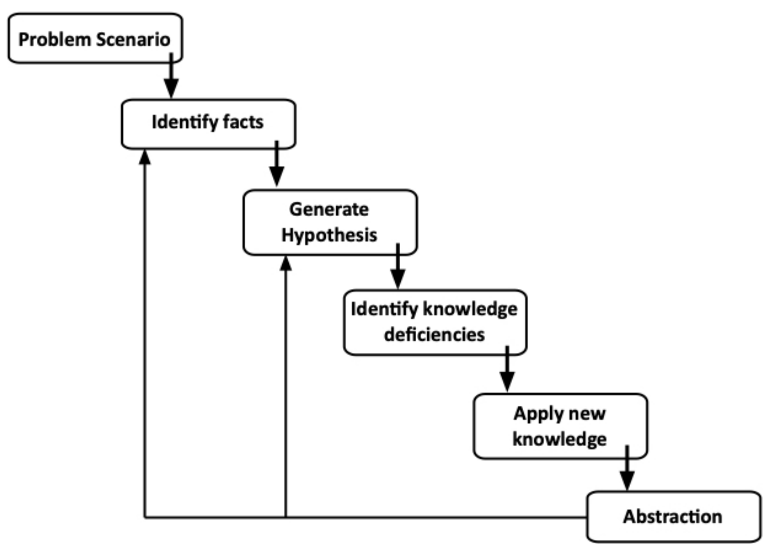
Apart from the theories that support learning in PBL, researchers have proposed learning models described in the following section. These models explain how PBL can be enacted in the classroom to meet the learning objectives.

4.5 Models of learning proposed by researchers

Many researchers have proposed models of learning in PBL (Flynn and Biggs, 2012; Overton et al., 2009; Hmelo-Silver, 2004). Most of these models involve understanding the problem, acquiring the relevant knowledge for problem-solving followed by executing the idea and finally reflecting on the entire process.

Elaborating on the learning cycle for the PBL process proposed by Hmelo-Silver, 2004 is depicted in Fig 4.2. The students encounter the problem scenario as the first step, followed by the identification of the relevant facts to analyze the problem, leading to the representation of the problem as they understand it. Once there is clarity on the problem and the possible solution, they generate the hypothesis. The next important step in this cycle is the identification of the knowledge gaps known as the learning issues which are filled through self-directed research. The acquired knowledge is applied to evaluate the hypothesis leading to the possible solution to the problem. This process is followed by a reflection of the abstract knowledge gained. Thus, the students manage their learning goals and engage in problem-solving through self-directed learning.

Figure 4.2: PBL model of learning proposed by Hmelo-Silver



Since PBL is backed by strong theory and robust models suggested by educationists and researchers, this instructional approach is adopted in many domains including the undergraduate chemistry laboratory. The following section briefly describes the PBL approach adopted in the undergraduate chemistry laboratory.

4.6 PBL in undergraduate chemistry laboratory education

Researchers have tried to understand how PBL could be applied to the context of an undergraduate chemistry laboratory with the motive to shift the current exposition-based approach to an inquiry-based approach.

Ram, 1999 used the PBL approach for undergraduate chemistry laboratory and based on her study she concluded that an authentic and challenging problem from a real-life context not only motivates students but also makes them enjoy the learning process. Similarly, Mc Donnell et al., 2007 found that there was an increase in class participation and class morale when stimulating real-life problems were used by him in PBL mini-projects for undergraduate chemistry laboratory courses. Contrasting this, McGarvey, 2003 noted from his studies, that inadequate staff experience with PBL may lead students to view PBL as time-consuming, frustrating, and intellectually demanding. He further suggested that to make it stimulating and interesting, adequate exposure of supervisors to PBL as an alternative is necessary.

Belt et al., 2005 developed some forensic case study modules for undergraduate chemistry courses that were received well by students which encouraged them to develop some more core chemistry modules. To situate PBL in a real-life context, Overton et al., 2009 developed modules in interdisciplinary areas like analytical, forensic, environmental, and pharmaceutical chemistry as getting a real-life context is easier in these domains. Kelly and Finlayson, 2007 have converted some of the traditional core chemistry laboratory modules to PBL modules for undergraduate chemistry courses and concluded that PBL fosters enhanced conceptual understanding through collaborative work. However, in general, core chemistry laboratory PBL modules are difficult as the real-life context is not obvious and therefore sparse (Overton et al., 2009). Thus, the design and development of PBL-based modules for core chemistry undergraduate laboratory and a study for its implementation in the existing chemistry laboratory appears to be one of the promising areas for research. The PBL approach is applied to laboratory work as well which can be executed under three parts namely, the pre-lab, lab, and post-lab work. The pre-lab component gives affordance for students working in small groups to understand the problem statement, hypothesize and design the experiment. The lab work in PBL typically guides students toward collecting data, the interpretation of which will help them in suggesting a solution to their problem. Post-lab is related to reflecting on the process and solution arrived at during the problem-solving process.

4.7 Factors leading to ineffective PBL

Boud et al., 2013 describe several pragmatic issues that may make the adoption of the PBL style in regular curriculum ineffective. The following paragraph lists some of these issues.

1. This instructional approach intends to develop independent learners who are good problem-solvers with great collaborative and communication skills and are divergent and creative thinkers. There is a possibility that the teaching strategy employed might or might not include what is defined to be a problem in PBL even though the other prescriptive aspects are followed. One should recognize the totality of the PBL style and not some of the aspects.

2. It is also possible that in the pursuit of PBL, the training may end up in mechanical practice while the stimulation required for deeper, holistic, and creative thoughts is lost. The facilitators who cannot resist the urge to give their knowledge and insights may result in such ill-structured interventions.

3. Students may assume the task to be related only to finding the solution so, instead of

a deeper engagement with the sources of information they may end up with primitive problem-solving in which case the cognitive involvement is also reduced. One way to mitigate this is to make the learning outcomes clear to the students and orient the assessment in the direction of the expected learning outcomes.

4. The students moving from secondary to tertiary level of education may not be adequately motivated for the kind of self-directed learning that a PBL demands. The facilitator's role is of utmost importance in providing support through their enthusiasm for teaching and taking care of the affective domain of students.

5. The outcomes of PBL may be negative if students acquire misconceptions or are unable to organize the knowledge gathered through various resources.

6. Kirschner et al., 2006 have criticized minimally guided instructions like inquiry-based, problem-based learning, etc. arguing that they do not take into consideration the cognitive architecture involving the working memory overload. They suggest that the underlying assumption that learning is more effective if students construct their knowledge, which forms the basis for the instructions such as PBL, and discovery learning, is flawed.

   These instructional styles ignore the interactions between working memory and long-term memory which eventually leads to learning. Since working memory is limited in duration and capacity, problem-solving places a huge burden on working memory, and thus the accumulation of knowledge in long-term memory is hindered whereas long-term memory is the central and dominant structure of human cognition which incorporates an enormous knowledge base. Further, they contend that all instructions aim to alter long-term memory which is less likely to happen if the limits of working memory are ignored as in the case of inquiry-based learning and PBL. Thus, strong guidance is imperative for effective learning to happen claim the authors.

In addition, there are some challenges which are identified by Chen et al., 2021 which they classified as challenges at institutional level, individual level and cultural level. Some of them are, a)lack of training as facilitators b)challenges of assessment, c)difficulty levels of problems, e) Lack of skills in teamwork, self learning, project management, f) lack of support from department or institution level, g) language barriers for non-native students. Since these factors can prevail in any challenging task such as PBL, appropriate scaffolding can be designed for success in the PBL approach.

4.8 Scaffolding for success in PBL

In a detailed response to Kirschner et al., 2006, Hmelo-Silver et al., 2007 refute them by stating that their claim of PBL "does not work" is not well supported. They further quote the theoretical and empirical evidence that suggests that PBL works because it is adequately guided through scaffolds. Collaborative learning and the key role of the facilitator acts as effective strategies for making the tasks, that are otherwise beyond the current abilities of the learner, accessible and manageable. According to Hmelo-Silver et al., 2007, "*Scaffolds redirect student's attention to important learning goals such as examining counterclaims, articulating explanations, and reflecting on the progress. . . .. PBL approaches involve the learner with appropriate scaffolding in the practice and conceptualization of the disciplines and in this way promote the construction of knowledge we recognize as learning.*" Thus, it is important to use an optimally guided approach (using appropriate scaffolds) for designing PBL modules. The following section deals with the scaffolds that the researchers have suggested and have used to facilitate PBL to make the approach successful.

4.8.1 Scaffolds and scaffolding strategies

Researchers view scaffolds as tools that support learning. Scaffolds help students to articulate and reflect while completing a PBL task Hmelo-Silver et al., 2007. Scaffolds can be soft scaffolds that include peer/teacher interactions and hard scaffolds which include artefacts/worksheets (Choo et al., 2011). Hmelo-Silver et al., 2007 describe in detail the scaffolding strategies to support disciplinary thinking and to provide expert guidance. They suggest that structured tasks, tools, and artefacts such as whiteboards, storyboards, etc. can be used to reduce cognitive load. Though Van Der Stuyf, 2002 claims that developing scaffolds to meet the needs of individual students is difficult, Quintana et al., 2018 contends that the scaffolding strategies lead to sense-making, process management, articulation, and reflection. According to Greenfield, 1999, *"scaffolds provide support, function as a tool, and extend the range of learners to accomplish tasks otherwise not possible individually"*.

A good scaffolding strategy involves, integrating, and distributing the scaffolds across the task. Additionally, when scaffolds are presented in multiple formats students can take the advantage of the affordances of the scaffolds. Scaffolds must be designed wisely as excessive or insufficient support can hamper the learning process. It is crucial to design the right kind of scaffold and provide it at the appropriate time during the task. Hints, prompts, thinking aloud, cue cards, feedback, process worksheets, checklists, leading questions, and part answers are examples of support that can help students accomplish the given task.

Authors further contend that the scaffolds work because they can be linked to the Vygotskian Zone of Proximal Development and thus the cognitive gap can be bridged with the help of scaffolds.

4.8.2 Types of scaffolds

There are hard and soft scaffolds. Hard scaffolds could be in the form of conceptual and strategic support. Conceptual scaffolds are prompts or cues that direct the student towards the ideas to consider. Strategic support helps to manage and organize the information collected by the students. Strategic support could be presented in the form of a video clip of an expert discussing the strategies (Hannafin et al., 1999). Hard scaffolds generally impact information seeking, task integration, and knowledge acquisition.

Choo et al., 2011 suggest that hard scaffolds are static tools such as the computer and worksheets with process charts. The worksheet could contain a hint that the students may consult while they engage in the problem-solving process. Simons and Klein, 2007 found that the hard scaffolds (strategic and conceptual) which included guiding questions, link to resources, and a hint screen helped students in the treatment group to perform better than the control group. One of the objectives of the study was to free the teacher from providing soft scaffolds and the authors suggest that in the absence of soft scaffolds, hard scaffolds may have a positive effect. They conclude that the scaffolds are valuable instructional tools and play an important role in improving the student's performance. Contrasting this view, the study by Choo et al., 2011 examined the effect of the worksheet as a scaffold on the student's learning achievement in the PBL environment and concluded that there was no statistical difference between the experimental and the control group. Further, they consider the importance of soft scaffolds that is the teacher and peer interaction to be crucial in line with the literature.

In contrast to the results from the study by Choo et al., 2011, Scaffolds in multiple formats should be distributed across the task so that students can best utilize them claim Puntambekar and Hübscher, 2005.

One of the important scaffoldings could be extended by peers who provide motivation and force one another to think. However, peer interaction may not be successful if the partner is competent but less confident. If peer support is not adequate it may not be very useful contend Fretz et al. 2002 (in Puntambekar and Hübscher, 2005). Further, the authors caution that, instead of assuming the cognitive benefit of pairing a learner with a more competent peer, we have to be mindful of the interaction between them.

4.8.3 Scaffolding PBL in the undergraduate chemistry laboratory

Agustian and Seery, 2017 state that an undergraduate chemistry laboratory is a complex learning environment because a laboratory has all the three components that define a complex learning environment i.e. a) the integration of knowledge, skills, and attitude, b) coordination of qualitatively different constituent skills and c) transfer of learning to a real setting. Thus, an appropriate scaffolding strategy needs to be adopted. Resorting to the cognitive load theory, the authors strongly recommend pre-lab work which has a two-fold benefit. One, pre-lab tends to reduce the cognitive load of the work that needs to be accomplished in the lab. Second, the pre-lab component itself acts as a scaffold for the lab work and within the pre-lab, various strategies can be adopted to further support the learning environment.

The three ideas suggested by the authors include; simple to complex strategy, whole task strategy, and just-in-time strategy.

Simple to complex strategy: This strategy is based on the recommendation by Van Merriënboer et al., 2003, who suggest that a simple learning task can precede a complex task to alleviate the problem of excessive cognitive load by a highly complex task. Another strategy is to adopt a part-task approach wherein the whole task is broken into parts and the students are presented and trained separately on these part tasks.

Whole task strategy: This strategy is aimed to develop a holistic vision of the whole task. Such a perspective may help students to connect the various steps or parts to what is expected to be achieved through the entire task.

Just-in-time: Apart from the generic scaffold prescribed for complex tasks, task-specific scaffolds are also important to suggest Van Merriënboer et al., 2003. Relevant literature, and supporting literature fall under the category of task-specific scaffolds. Shultz and Li, 2016 report that students, in general, do not demonstrate the skills related to seeking and evaluating information. In turn, the new knowledge required for problem-solving is neither available nor integrated into their knowledge base. Thus, in the absence of literacy skills, students need to be given task-specific information to scaffold their learning. This information need not be the algorithmic description of how the task has to be performed rather it provides heuristic knowledge that may help perform the non-recurrent aspect of the task such as reasoning and problem-solving. One way to provide the heuristic knowledge is by giving an equivalent learning task that may help develop an understanding of the principles underpinning the task. For the tasks which can be performed as routine or recurrent tasks, the procedural information can be given just in time when the students are at it on problem-solving the task. In contrast, the supporting information of the task should be given prior to the task as it can encode in the long-term memory and is available in the working memory whenever students need it. Thus, the use of an effective pedagogy with carefully planned scaffolds can help students accomplish success in cognitively complex tasks such as PBL.

4.9 Summary

Inquiry-based learning and PBL are different in terms of whether the style is driven by a question or a problem. Inquiry-based learning leads students to learn the methods of science. On the other hand, the core concept of PBL is to engage students in problem-solving that leads them to learn content and the process as well. A carefully designed problem helps students assume their responsibility for learning and the teacher facilitates such self-directed learning.

Many theories support PBL instruction. This study is inclined towards Kolb's ELC as the theoretical framework as it informs the way to plan and sequence the scaffolds.

The conceptual and theoretical framework presented in this chapter helped in gathering understanding for the development of an inquiry short course on indigo dye that featured a scaffolded PBL laboratory module which is described in the following chapter.

Chapter 5

Design of indigo short course

5.1 Overview of the chapter

Most of the colleges of Mumbai and Pune region follow a conventional instructional style and do not have any inquiry-based experiments (Chapter 3 Section 3.1.7). On the other hand, the CER literature states the need of using inquiry-based approaches to engage students in higher-order cognitive tasks. The merits of using such approaches have been discussed through numerous research studies over the past five decades and proposals to introduce inquiry-based approaches as an alternative have been emphasized (L. D. Bruck and Towns, 2009; Maeng et al., 2013; Weaver et al., 2008; Wheeler et al., 2017) This chapter describes the design of a short inquiry-based laboratory course and its instructional design that was followed for the implementation and data collection for the research study.

5.2 Design of the short laboratory course

The short lab course was developed using indigo dye as the central theme. The course was developed with the design principles to a) provide a real-world context, b) introduce inquiry incrementally c) integrate different domains of chemistry, and d) provide an opportunity for the development of science practice skills and decision-making. These overarching principles guiding the design of the course with indigo dye as the central theme are detailed below.

5.2.1 Indigo as real-world context

Indigo dye is widely used for dyeing the fashion clothing of students, i.e. denim, providing a real-world familiar context. Overton et al., 2009 suggests that a familiar context can be motivating to students in their process of learning. Additionally, a visual colour change associated with the instant aerial oxidation of yarns dipped in a yellow-coloured leuco-indigo bath to blue colour is equally fascinating to motivate learners.

Indigo as a dye is known since ancient times. It has an interesting history in the Indian context. During the British era, the exploitation of indigo planters started the Bengal revolt.

The dyeing process has environmental concerns. Indigo is a vat dye and uses multiple chemicals such as sodium hyposulphite, sodium hydroxide etc. which causes pollution. These facts were used to introduce real-life problem-solving context.

5.2.2 Introducing inquiry incrementally

The transition from verification to inquiry labs may be challenging for students (Bopegedera, 2011). It is important to make the transition smooth for novice students from the conventional laboratory to the tasks that intend to involve higher levels of inquiry (Van Wyk et al., 2022; Cacciatore, 2014; Schoffstall and Gaddis, 2007). Due to this factor, an incremental approach to introducing inquiry was considered essential.The short course consisted of four different lab tasks that introduced inquiry incrementally.

Laverty et al., 2016 contend that students' engagement with inquiry tasks helps them eventually in applying the acquired scientific knowledge in, –a) developing models, b) explaining phenomena, and c) designing a solution to problems.

The levels of inquiry (Buck et al., 2008) guiding the design of the short course are described in Table 5.1. The first two experiments of the short course were designed to comply with the level-1 inquiry. The third and fourth experiments were presented as a level-2 PBL inquiry approach.

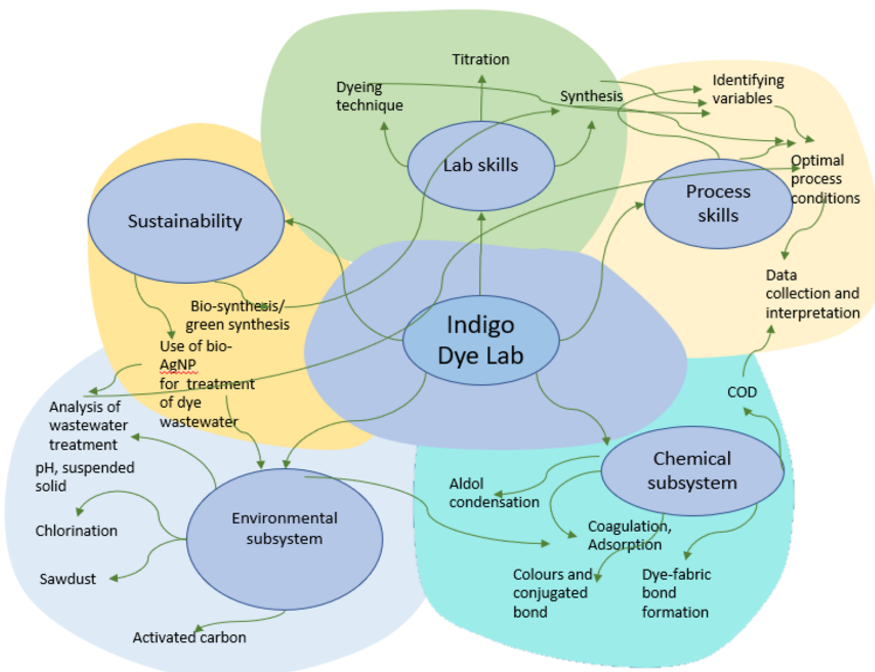
Table 5.1: Levels of inquiry of different indigo dye experiments

Description	Synthesis of indigo	Dyeing of yarn with indigo	Analysis of indigo wastewater	Treatment of indigo wastewater
Level of inquiry	Level-1	Level-1	Level-2	Level-2
Problem / question / aim	Provided	Provided	Provided	Provided
Theory/ background	Provided	Provided	Provided	Provided
Procedure / design	Provided	Provided	Not Provided	Not Provided
Result and analysis	Not Provided	Not Provided	Not Provided	Not Provided
Result communication	Not Provided	Not Provided	Not Provided	Not Provided
Conclusion	Not Provided	Not Provided	Not Provided	Not Provided

5.3 Integration of different domains of chemistry

The design of the course is influenced by the systems thinking approach which advocates the teaching-learning of concepts with a holistic perspective (Orgill et al., 2019). The systems thinking approach recommends context-based experiences which are known to motivate students, thus, bringing greater relevance and interest to their learning. It also gives opportunities to connect and understand various subsystems that constitute complex systems (Aubrecht et al., 2019). The interconnections are generally represented through a SOCME diagram which are visual tools to conceptualize complex systems (York and Orgill, 2020). The SOCME diagram (Fig. 5.1) describes the dynamic relationship between different domains associated with indigo dye tasks. In this diagram, the various subsystems are indicated in blue ellipses. The components belonging to a specific subsystem are bound by the coloured patches. The connections between the subsystems are represented by curved arrows.

Figure 5.1: SOCME diagram for indigo dye lab representing the connections of various sub-systems of the indigo lab.



The short course integrated different domains of chemistry such as organic chemistry (synthesis of the dye), applied chemistry (dyeing of yarns), and environmental chemistry (analysis and treatment of wastewater as detailed in Table 5.2. The content, the key concepts and skills (science practice and procedural) covered as a part of the different lab tasks are presented in Table 5.2

Table 5.2: Concepts, skills, and chemistry contents of the modules

Experiment	Content	Key chemical concepts	Science practice skills	Lab / procedural skills
Lab-1 (Organic Chemistry)	Organic synthesis of indigo dye	Aldol Condensation	Identifying factors affecting the synthesis	Related to organic synthesis, e.g., vacuum filtration, washing, etc.
Lab-2 (Applied Chemistry)	Use of synthesized indigo for dyeing yarn	Role of conjugated bonds in coloured chemical substances, binding of chemical dyes with fibres	Identifying the factors affecting the dyeing	Calculations involved in obtaining a specific % shade, Dyeing technique.
Lab-3 (Env. Chemistry)	Analysis of wastewater from indigo dyeing	Chemical Oxygen Demand (COD)	Data collection and interpretation	Titration (redox and back titration).
Lab-4 (Env. and Physical Chemistry)	Treatment of wastewater from indigo dyeing	Coagulation, Adsorption	Identifying the optimal conditions for wastewater treatment	Determination of optimal amount of coagulant and adsorbent for effective treatment

The role of conjugate bonding in imparting colour, concepts of wastewater characterization, coagulation, adsorption, COD, etc. were the chemical concepts introduced through these modules. Any wastewater with a high COD value discharged into streams will eventually result in the depletion of dissolved oxygen. That is why it is an indicator for understanding the level of pollution. In the case of indigo dyeing, the wastewater has high COD values due to the nature of the chemicals used in this process. The efficacy of the suggested treatment had to be established by analyzing the wastewater before and after the treatment, especially for the COD value.

5.4 Science practice skills and decision-making

Another important feature of the course was to provide an opportunity to develop science practice skills such as a) formulating hypotheses, b) planning and carrying out investigation, c) constructing explanations and engaging in arguments, d) data collection and evaluation, e) results and discussion. The incorporation of these skills in the indigo module is described Table 5.2). The first two experiments required students to identify variables and formulate a hypothesis. Depending on the chosen variable, students had to plan the experiment, collect data and (dis)prove their hypothesis. More importantly, they were expected to discuss the results. The third and fourth experiments were based on a PBL approach and the students had to devise an experimental design (ED) to find a viable solution for discarding the wastewater generated through the process of synthesis and dyeing of indigo. Thus, with the incremental inquiry level as well as by engaging students for a longer duration, these science practice skills namely, hypothesis generation, experimental design, analysis, interpretation and discussion of data and results were introduced gradually and spread over the four inquiry tasks.

For experiments involving the synthesis and dyeing of yarns, students were given opportunities to decide and make a choice of the variables affecting the outcome of the experiment. Multiple procedures were provided to students to identify and choose the one that is better from the perspective of green chemistry and cost-effectiveness. For example, for lab 3, two titrimetric procedures for determining the COD were included in the reading material which varied in terms of energy usage, time consumption, and quantities of chemicals. The purpose was to provide opportunities for students to consider these factors while designing their experiment on wastewater analysis. Further, multiple treatment methods including a low-cost adsorbent and expensive adsorbent were included in the reading materials to draw students' attention to economics versus effectiveness thereby engaging in critical thinking and prudent decision making.

5.5 Instructional design

The following section describes the instructional design with a detailed plan for the execution of the prelab, lab and post-lab for each lab task.

5.5.1 Lab-1: Synthesis of indigo dye

The first experiment on indigo synthesis involved aldol condensation as a concept introduced through theory sessions. The synthesis utilizes 2-nitrobenzaldehyde, acetone, and sodium hydroxide (McKee and Zanger, 1991). The aim of the experiment and the procedure for synthesis was provided in the reading material. During the prelab, students had to engage in classroom discussion to identify variables that would affect the yield of the dye and then carry out the experiment to check their hypothesis (after safety considerations). The procedure was relatively simple and the number of possible variables that could affect the yield was also limited. This led to less complex tasks and a lower level of inquiry.
During lab work, the students were expected to conduct the experiment based on their hypothesis. The procedure for synthesis does not entail special lab techniques/skills and primarily involves careful mixing of chemicals in stoichiometric proportions with stirring. It was expected that the students collect the wastewater from the dye synthesis for further work. During post-lab, students had to interpret the data and write the report.

5.5.2 Lab-2: Dyeing of yarns

The air-dried indigo dye, synthesized in the first experiment, was to be used by students for dyeing yarns. As compared to the synthesis lab, this lab needed greater interactions with the facilitator as concepts and procedures related to the dyeing of yarn are new knowledge to students. The level of inquiry was the same as was in the first lab. However, this task had enhanced complexity in terms of the number of variables, the time needed for the completion of the task, the new knowledge, and the skills to be learned.

Figure 5.2: Leuco-indigo dye bath of different concentration(experiment on effect of varying percentage shade on yarn dyeing

)

The procedure for dyeing demands students to decide the required percentage shade as well as an understanding of the mathematical calculation for the preparation of the stock solution, blank vat, dye bath, etc. Though it is not difficult to identify the variables in the process of dyeing, the calculations and preparation of solutions depending on the chosen variable are challenging. Video and actual demo sessions were carried out to show the technique. All these activities were a part of the prelab. Students need to be given optimal guidance to maintain the inquiry level and the instructor needs to be mindful of the complexity of the task.

Additionally, a short problem-based task was introduced asking students to design a technique for comparing the shades of the yarns obtained from the dyeing process as the shades are bound to vary due to the variables chosen by students.

Figure 5.3: Variation in the intensity of colour of yarn dyed by the students.

The lab work entails the preparation of various solutions of desired strengths based on the hypothesis (such as sodium dithionite, sodium hydroxide and indigo solutions). Students were expected to dye the given yarn by dipping it in the leuco-indigo dye solution and lifting it in the air for aerial oxidation. Aerial oxidation cause the colour to instantly start changing from yellow to blue. The intensity of the colour on the yarn varies based on the parameters chosen. Students were expected to compare the dyed yarns visually. After the dyeing process, the resulting wastewater was preserved by students for the subsequent labs 3 and 4. Similar to lab task-1, students were expected to interpret the results and write the lab report.

5.5.3 Lab 3 and 4: Analysis and treatment of the wastewater

The PBL approach of lab-3 and 4 involved level 2 of inquiry. These labs required students to generate an Experimental Design (ED) for the analysis and treatment of wastewater followed by the interpretation of the collected data. To support learning in the PBL format, the following three scaffolds were provided to students (Table 5.3).

Table 5.3: Scaffolds provided to students

Scaffold	Pedagogical purpose	Stage in the Kolb's Cycle (Ref.Chapter 3)
Precursor-task	Help students in logical sequencing of experimental processes	Stage-1: Concrete Experience (CE), developing a simple experimental design
Reading material	Provide pre-requisite knowledge for the PBL task	Stage-1: Concrete Experience (CE), accessing and acquiring prior knowledge
Structured group discussion	Engage students in reflective thinking	Stage-2: Reflective Observation (RO), leading to Stage-3 i.e., Abstract Conceptualization (AC)

5.6 The PBL task and scaffolds

Precursor Task

A precursor task, given in Appendix E, was designed to help students get exposure to planning a PBL experiment. The task involved designing an experiment to determine the most suitable vinegar (of the ones available in the market) for usage in pickles. The task sheet defined the problem and gave clues to use the information provided in this sheet. One of the pieces of information included as a clue was that the vinegar should be of strength 5% v/V for its suitability for use in pickles. Students had to plan an acid-base titration with sodium hydroxide, which they are familiar with. The expectation was that the students would decide, a) the glassware to be used, b) the volume and concentration of sodium hydroxide, c) the cleaning of the glassware, and d) the calculation to convert either % strength to Molarity or Molarity to % strength.

The purpose of this scaffold was to introduce students to PBL by having them plan a simpler preliminary task for concrete experience and to act as a bridge to a more complex indigo PBL inquiry. The precursor task was limited to experimental design and students were not expected to perform any lab work.

Reading Material

The second scaffold, a reading material (Appendix F), was designed to present the prior knowledge required for the indigo dye investigation. The history of indigo, mechanism of synthesis, vat dyeing, wastewater characterization, etc. which was provided in the reading material is not a part of any of the students' previous curriculum in school/college.

The compiling of contents was expected to help students construct prior knowledge who have no prior exposure to such information.

The indigo reading material required students to reflect on the content while reading. Students were given prompts such as a) important information needed for planning the laboratory work, b) already known information, c) information that discusses theory/concept related to the task, d) useful background information related to the task, and e) information that needs further reading. Space was provided along the margin for them to make notes.

Though the reading material was sufficient in its own right, the students had the freedom to explore beyond the reading material and browse the internet for further information.

Structured Group Discussion

Students were provided with an opportunity to engage in dialectic conversation (reflective observation) to express their ideas. The purpose of structuring the group discussion was to include the ideas from all student groups. This structuring is described below.

- After going through the reading material, students were expected to discuss and finalize the ED with their team members without the intervention of the facilitator. (However, the facilitator needed to make a judgment of the clarity and completeness of the initial ED by each of the teams).

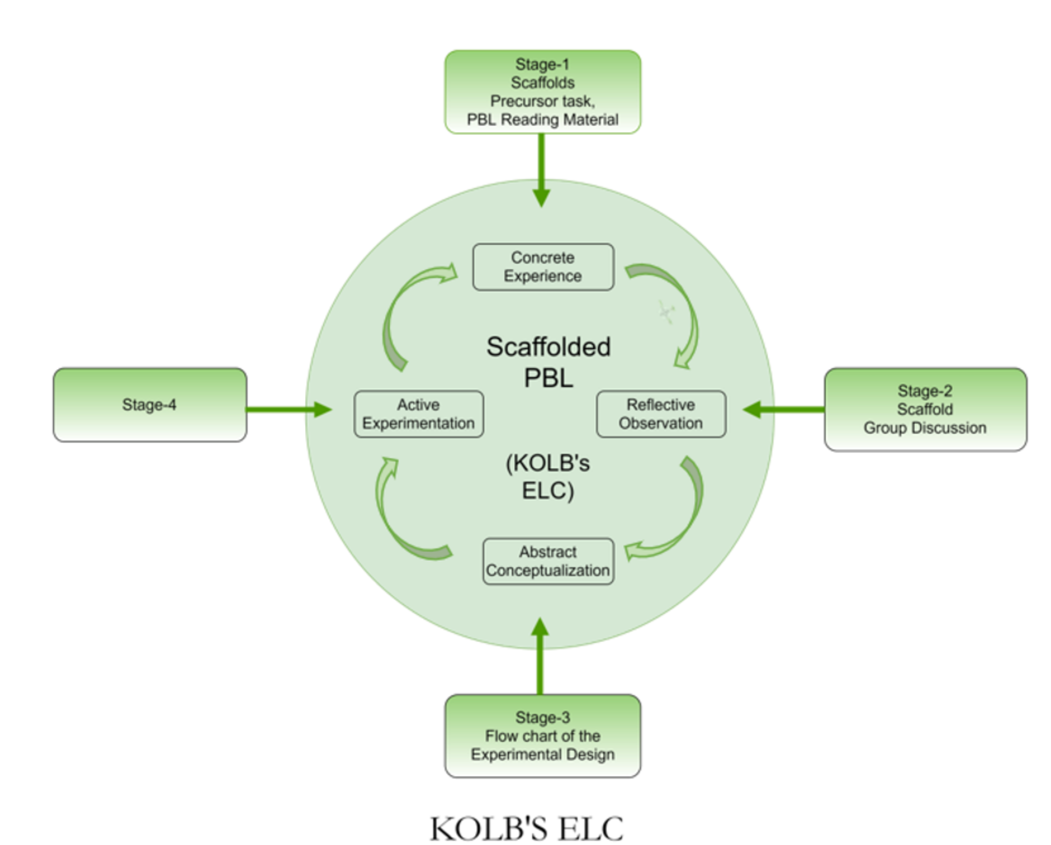
- Each small group was expected to present its initial design to the rest of the small groups. The least comprehensive experimental design was to be presented first followed by the others in the order of increasing comprehensiveness. The objective of such an order of ED presentation is to ensure equitable discussion of all ideas. The structured discussion helps students to realize how their plans could be improved both incrementally and overall.

Through the structured group discussion, students were expected to reflect on EDs and identify flaws in their initial plans to modify them.

5.7 Sequencing of scaffolds as per Kolb's ELC

These scaffolds for lab tasks 3 and 4 were sequenced according to Kolb's Learning Cycle Figure (5.4).

Figure 5.4: Scaffolds sequenced as per Kolb's ELC.

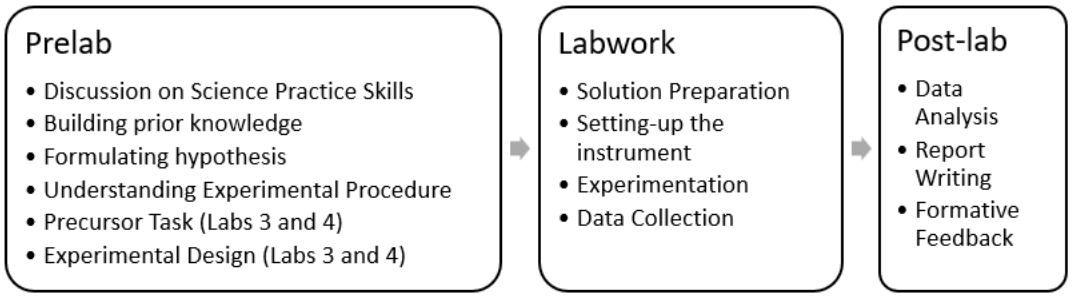


As per Kolb's ELC, students need to go through four stages namely, the Concrete experience, Reflective observation, Abstract conceptualization and Active experimentation. The first scaffold was the precursor designed to give students a concrete experience of planning an experimental design. Students also get a concrete experience of accessing and assessing the required knowledge for the task through the information provided in the reading material. After the concrete experience, the students get an opportunity to reflect on their initial experimental design when they present it to the other groups which engage in argumentation leading to the construction of an explanation. Reflective thinking helps students to modify their EDs and develop an abstract conceptualization of the overall task which is presented through the flow chart. The prelab for lab tasks 3 and 4 were planned for a longer duration as compared to labs 1 and 2. During the prelab work, students had to– a) devise the experimental plan for a precursor task, b) demonstrate an understanding of the content of the reading material for the indigo task, c) formulate an experimental design (ED) for analysis and treatment of indigo dyeing wastewater, and d) construct a flow chart of the process.

The students had to choose parameters for analysis (e.g., pH, colour, COD) and suggest a method to treat the wastewater. Activated carbon (AC), liquid alum, and sawdust were made available as possible materials for the treatment of wastewater.

The EDs are then implemented in the lab through active experimentation leading to a collection of data. During the lab, students prepared the solution, carried out the investigation, and collected data. The post-lab work involved analysis, report writing, and formative feedback on the reports. The following section presents the details of activities carried out in the prelab, lab, and post-lab work (Figure 5.5).

Figure 5.5: Contents of prelab, lab, and post-lab



Lab task sheet for lab 3 and 4

After the group discussion, students were given task sheets for prelab, lab and post-lab work (Appendix G) which contained questions and prompts. The content of these is explained below.

Prelab sheet

The first question was to help them pen down the information they gathered through the reading material and what they think they need to gather further. This question was followed by asking them to write the parameters chosen for wastewater analysis and the reason for their choice. They had to then choose the required glassware and chemicals from the given list. Task sheet had space where students were asked to write their plans both in textual and flow chart format and then cross-verify from the pointers. The next question was to pen down the safety measures they would take in the lab.

Lab sheet

This sheet was provided to them when they started their lab activity. The first pointer asked them to draw the data table for the lab trials. The second pointer in the form of a table provided three columns to enter the parameters they analyzed, the permissible limit for that parameter in the wastewater for discharge into the water body and then the value they found for that parameter before and after the treatment. This table was to help students compare and interpret the results obtained by them.

Post lab sheet

The post-lab sheet was to help them with the report writing. Two kinds of pointers were given to different groups of students to understand which one of the two is more helpful to students to write the report. The first set of pointers is called the Science Writing heuristics (SWH) and the second set is named the Lab Report Pointers (LRP, Appendix H). These are described in Table 5.4. SWH report provides pointers in question format to elicit the report of lab work. The LRP pointers combined the reporting pointers given to students in a conventional laboratory and the inquiry lab. Since the pointers are open-ended, students could write as much as they deem appropriate rather than restricting themselves to just writing the answers to the questions in SWH.

Table 5.4: Pointers for writing lab report

SWH Questions as prompts (for workshops -1,2, and 3)	Lab Report Pointers (LRP) as prompts (for workshop-4)
What are my questions? What did I do? What did I see? What can I claim? How do I know? Why am I making these claims?	Aim Materials Theory Hypothesis/Research question Procedure Quantitative observations Qualitative observations Results Discussion

5.8 Summary

The chapter highlighted the design of the indigo module. The overarching principles of the design were a real-world context, incremental levels of inquiry, science practice skills, decision-making, and integration of different domains. The chapter also described the instructional design of how the short course was implemented. There were four experiments and each of the experiments entailed prelab, lab and post-lab work. These experiments varied in the levels of inquiry.

After the design of the short course, two kinds of studies were carried out. The first one was to understand the role of scaffolds in devising the experimental design. The second study aimed to understand the impact of the short course designed with an incremental inquiry approach on science practice skills. The research methodology of these two studies is presented in the following chapter.

Chapter 6

Research Methodology

6.1 Overview of the chapter

The research work included two major studies. Study 1 explored the role of scaffolds in enabling students to devise experimental design(s) for the indigo PBL task through a quasi-experimental research design. Study 2 adopted a case-study design to understand the impact of the incremental levels of inquiry on the science practice skills of students. This chapter presents the methods used for these two studies including the research questions, the rationale for the choice of methodology, ways to evaluate students' responses in the data, rubrics for assessment of experimental design (ED) and for lab reports. The validity and reliability measures taken for data analysis are also discussed in the chapter. Both the study followed the qualitative approach for data collection and analysis, however, to determine the participant equivalence and for inter-rater consistency (between the evaluators who gave scores to EDs), statistical tests (Kruskal Wallis and Mann Whitney) were used prior to the data analysis. These two tests are non-parametric version for comparing multiple groups and two groups respectively. They are equivalent of ANOVA and t-test of parametric version.

6.2 Study 1: Exploring the role of scaffolds for devising experimental designs (ED) in PBL task

Experimental design (ED) is a key inquiry skill in an undergraduate laboratory and often students struggle with formulating EDs (Shi et al., 2011). In addition, ED has a precedence to the lab task. Even to begin a lab work, experimental design is required. In an inquiry task such as the PBL, it is expected that the students devise their EDs for solving the given problem. The importance of students' understanding of experimental design is established in CER literature, however, there are scant research studies available to understand students' learning related to this aspect (Dasgupta et al., 2014).

This study involved understanding the impact of the scaffolds on the devising of EDs by students. Thus, Study 1 explored the following research questions.

6.2.1 The Research questions

RQ-1: Do scaffolds (precursor task, reading material, group discussion) help students improve the quality of their experimental design (ED) of a PBL task?

Since the scaffolds were sequenced according to Kolb's experiential learning cycle, the study also explored the following research question.

RQ-2: How do scaffolds help students move through the planning stages of Kolb's Experiential Cycle leading to meaningful learning?

One of the important scaffolding strategies in inquiry approaches such as POGIL, PBL, PLTL is collaborative learning. Students working in groups of 3 to 6 offer support required in their self-directed learning (Cen et al., 2016; Lohman and Finkelstein, 2000). Working in a group is a prescriptive aspect of PBL and it may be interesting to capture how students perceive the group work.

Thus, the third research question was,

RQ-3: What is students' perception of working in groups in the given PBL task?

The research questions entailed analysis of the written responses (EDs) of students. Further, the nature of the scaffold i.e. group discussion required transcribing the audio recording for analysis. The analysis also required mapping students' responses with the stages of Kolb's experiential cycle. The questionnaire given to students had open-ended questions on group interaction. Thus, the research questions required analysis of open-ended responses necessitating the qualitative approach to the study. Furthermore, the study retained a teacher-to-student ratio of 1:15 to match with what is followed in the undergraduate laboratories in the region where this study was carried out. Such numbers are better suited to the qualitative approach.

Study 1 adopted a quasi-experimental design because the study explored the scaffolds as an intervention in the experiment. There were two groups; one was the treatment group (scaffolded) which was provided with the problem statement along with the scaffolds as an intervention to understand the quality of EDs. The other was the control group (unscaffolded) group which was provided with only the problem statement and no scaffolds. The students in the control group volunteered for the study. This made the study to be a quasi-experimental design since the participant selection was not randomized for the control and treatment groups as required in a true experiment. The unscaffolded group was equivalent to the control group. The control group in this study is referred to as the unscaffolded group and the treatment group is referred to as the scaffolded group. The scaffolded and unscaffolded groups were equivalent in terms of their background and participation criteria, explained in detail in Section 6.2.3.

Since the scaffolds were expected to impact the EDs, the study analyzed the ED as an outcome of the intervention instead of conducting a pre/post-test. The criteria of the quasi-experimental design are given in Table 6.1.

Table 6.1: Quasi-experimental design

Group	Intervention	Outcome tested
Experimental group (Scaffolded group)	Scaffolds	Experimental Design
Control group(Unscaffolded)	No scaffolds	Experimental Design

The following section describes the research design in detail.

6.2.2 Research design

The research involved the participation of 75 first-year undergraduate students who had completed six months of general chemistry courses and had exposure to the traditional lab. There were four trials with these students, two in the Institute setting and another two in the Authentic setting of the student's home colleges. The unscaffolded group belonged to the Institute setting.

Figure 6.1: Research Design Study 1

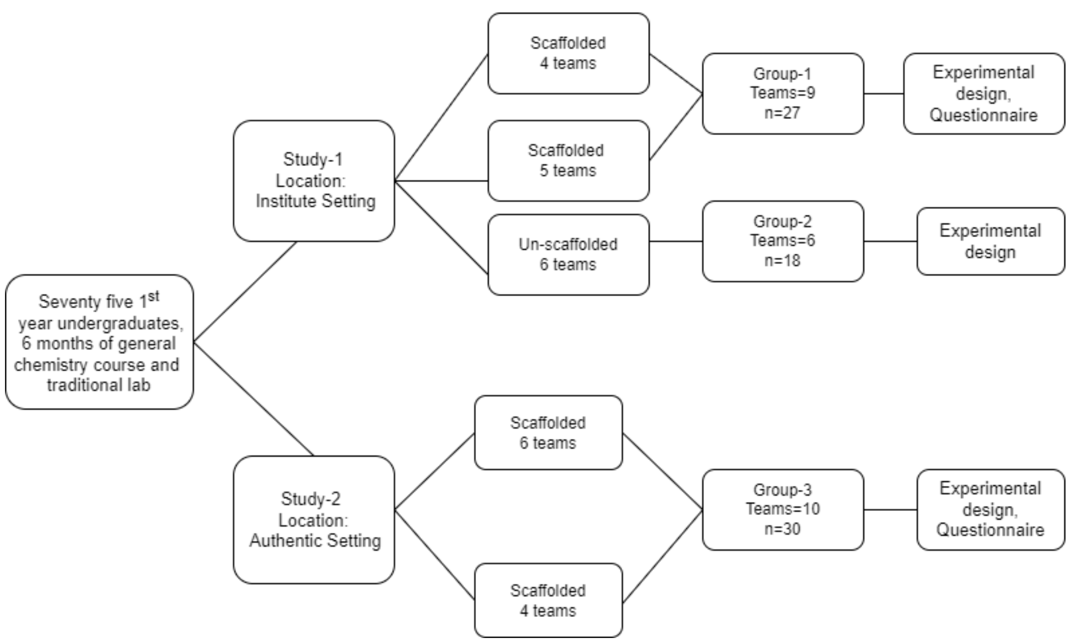


Table 6.2 presents the details of the trials.

Table 6.2: Trials for the study

Description	Study 1				
	Workshop-1	Workshop-2		Workshop-3	Workshop-4
Setting	Institute	Institute		Authentic	Authentic
Number of Participants	12	Scaffolded	Unscaffolded	18	12
		15	18		
Teams	4	5	6	6	4
Data for Study 1	Combined*(total teams = 9)			Combined*(total teams = 10)	
Data for Study 2	....NA...				Same cohort for Study 2

Combined* after proving the statistical equivalence

After the implementation of the module, EDs were collected as the data from all the trials.

The Institute Setting

The first research setting is the researcher's home institute where educational activities such as research, outreach programs, and winter camps for students are conducted. The institute holds workshops for students and teachers as a part of the National Initiative for Undergraduate Science (NIUS) programs which conduct workshops on theoretical and experimental science, develop pedagogical material and conduct research in science education/laboratory training. The focus of the student camp held every December, is to help them to expose inquiry-based experiments in the lab. This setting offered sampling convenience as first-year undergraduate students are invited to NIUS winter camp every year with the same selection criteria. The two trials in the Institute setting were planned during Dec. 2018 and Dec. 2019.

The Authentic Setting

The other two trials were carried out in the Authentic settings of the students' home colleges where undergraduate classes are held regularly. These trials were carried out to understand the transferability of the intervention used in the Institute setting. The workshops in authentic settings were conducted in two colleges that are affiliated with the same university (SPPU), follow the same prescribed syllabus and are located closeby. One of the two colleges is an established old college whereas the second one is relatively new. This difference offered an advantage as the established college was open to exposure to a pedagogical style different from their regular college practice. And, the new one was open to experimentation with the newer pedagogies. These colleges were selected based on the locational convenience of the researcher.

6.2.3 Participants

Forty and Fifty students participated in the NIUS program at the Institute in Dec. 2018 and Dec. 2019, respectively. For workshops 1 and 2, respectively, 12 and 15 students were randomly selected as participants for the scaffolded group. Students of the Dec. 2019 batch were invited to participate in the unscaffolded group voluntary basis. The researcher explained the purpose of the study to participants of scaffolded and unscaffolded groups. They were communicated that their experimental designs collected at the end of prelab would be compared. The students in the unscaffolded group were also communicated that they would get the opportunity to perform inquiry-based lab tasks other than the indigo task. The researcher answered clarificatory questions posed by students, following which, 18 students volunteered to be part of the unscaffolded group (Table 6.2). These students were from different colleges across India and had diverse cultural, social, and lingual backgrounds. To understand the academic equivalence of the participants, the scores of the 12th-grade public examination were compared. This academic score is a basic criterion for entry into an undergraduate course.

For the workshop in the authentic setting, the scaffolded group consisted of a cohort of 12 and 18 students, respectively. The number of students in each workshop was chosen to match the student-to-instructor ratio in the region where this study was carried out. The study did not have an unscaffolded group in the authentic setting as the college authorities required that all participating students be given the same learning opportunity.

All four workshops (Institute and Authentic) were conducted over a period of one year between Dec. 2018 and Dec. 2019. Informed written consent (Appendix A) was obtained from all the participants from both settings. Participants were grouped into **teams** (n = 3) for collaborative learning as prescribed in a PBL approach.

The facilitator of this task was a researcher with 20-plus years of teaching inquiry-based instructional material to students at secondary and undergraduate levels. Her role was to define the task, carry out the group discussion, and encourage peer interaction in case of any clarification was needed by students.

There was an option to combine the data from all four workshops and compare it with the data from the unscaffolded group since all the participants were first-year undergraduates. However, to understand whether the data from the four workshops could be combined or not, statistical tests were performed on the prior academic achievement scores. The 12th-grade public exam score which is a criterion for entry into undergraduate courses was used for this purpose. The academic equivalence among participants of the workshops was understood prior to the data analysis through two non-parametric statistical tests applied to the 12th-grade exam scores.

The first test Kruskal Wallis was performed to compare the 12-grade mean scores of scaffolded participants (treatment groups) of workshop-1 and 2 and the unscaffolded participant (control group) in the Institute setting. This non-parametric test helps identify whether the samples are drawn from the same population or not. It is non-parametric version of ANOVA. The second, Mann-Whitney test was performed to, a) check the equivalence of participants of workshop-3 and 4, and b) to check the equivalence of participants in the Institute and Authentic setting. Mann Whitney test compares two independent groups and is similar to t-test for independent samples of the parametric version. The results of these tests are presented below.

Table 6.3: Participant equivalence

Statistical test	Setting	Groups compared	Result	Remarks
Kruskal Wallis	Institute	Scaffolded (Dec.'18 and '19) and Unscaffolded	(H = 4.82, df = 2, p-value = 0.089)	Statistically insignificant
Mann Whitney	Authentic	College-1 and College-2	U = 93, $p < 0.001$,	Statistically insignificant
Mann Whitney	Institute and Authentic	Institute Scaffolded and Authentic scaffolded	U =75.5, $p < 0.001$, effect r =0.68	Statistically significant

These analyses helped to,

a) combine the data from two workshops within the Institute setting since there was no significant difference in mean scores of the 12th-grade public examination.

b) combine the data from two workshops within the authentic setting since there was no significant difference in the mean score of the 12th-grade public examination.

c) understand not to compare the data of the unscaffolded groups with the scaffolded authentic settings.

d) understand the need to separately analyze the data from the two settings.

The data from the scaffolded teams from two workshops within the Institute setting were combined. Likewise, the data from the two workshops within the Authentic settings were combined since the variables such as age group, chemistry background(theory as well as traditional nature of lab experience), facilitator, implementation, and intervention protocols were constant.

6.3 Validity of PBL module

The module was validated for the suitability of the content for first-year undergraduate students by four experienced chemistry teachers and have instructed lab courses as well. Two experts (both females) had backgrounds in analytical chemistry and had an experience of 2 and 10 years, respectively. The other two experts (one female and one male) had backgrounds in organic chemistry and experience greater than 20 years.

These teachers were randomly selected from a group of teachers who had come to participate in the capacity-building program at the researcher's home institute. They were given the problem statement and the selected research papers to build the required prior knowledge for problem-solving. They were also given internet access and were expected to work in a group. A day was given for them to devise the experimental design and the following day they carried out the lab trials and then write the reports. They performed the investigation the way it was planned for the students.

The teachers found the task appropriate for the first-year undergraduates both in terms of the content and experimental investigation. They expressed excitement about carrying out the inquiry task. Based on the experience, they suggested the following changes in the approach that were accepted by the researcher.

1. To compile the content to build prior knowledge.

2. To describe or give a demo of the process of indigo dyeing before students plan their EDs for the wastewater analysis and treatment,

3. To provide additional chemical (acetic acid) that can be used to alter the pH of the wastewater sample or to acidify activated carbon to be used for the treatment.

4. To video demonstrate the reflux procedure which was part of the determination of chemical oxygen demand.

After these modifications, rubrics for the scaffolds i.e., the precursor task, reading material, and structured group discussion were validated and checked for reliability. The rubric and its validation are presented in the next section. The profile of experts who validated the rubrics and the experts who evaluated the student's data is presented in Table 6.4.

Table 6.4: Expert profile

Description	Expert -1	Expert-2	Evaluator-1	Evaluator-2
Highest degree	Ph.D (organic chem)	Ph.D (physical chem)	Ph.D (Inorganic chemistry)	Ph.D (organic chemistry)
Years of experience of teaching undergraduates	32	6.5	(teaching master's course for 14 years)	25
Years of experience of developing/assessing similar modules like indigo or any inquiry-based	Mentored projects by students	2 modules on inquiry-based	14 (assessing the laboratory work)	31* (assessing the laboratory work)
Years of conducting laboratory course	32	6.5	14	31*

31*, additional 6 years experience other than teaching undergraduates

6.4 Method for evaluating experimental design (ED)

According to Dasgupta et al., 2014, the important features of ED are, formulating research questions, defining the experimental set-up, measurable variables, and visualizing the interpretation of results. Though many researchers (Helix et al., 2022, Dasgupta et al., 2014) have developed assessment schemes for ED in biological sciences there are few studies that describe the method for assessment of the quality of ED, especially in a scaffolded PBL task for undergraduate lab work.

In the present study, an assessment of the following aspect of ED was done through a rubric (Appendix I) developed by the researcher based on, a) understanding of the overall task, b) the variables chosen for the investigation, c) logical sequencing of steps, and d) tools for measurement. This rubric is close to the Experimental Design Ability, EDAT Test developed by Sirum and Humburg, 2011.

Table 6.5 maps the parameters of the rubric developed for the current study with some of the parameters included in the EDAT.

Table 6.5: Rubric vs Experimental Design Ability Test (EDAT)

Rubric designed for indigo ED	EDAT
Understanding of the overall task	Recognition that an experiment can be done to test the claim
The variables chosen for the investigation	To identify what variable is manipulated
	Define how independent variable be manipulated
	Dependent variable identification
Tools for measurement	Measurement of the dependent variable
Optimization	Understanding that the experiment needs to be repeated

A rubric was created to assess each component of ED such as the module objectives (wastewater analysis, treatment, and optimization), the logical sequence of steps (flow chart), quantities and concentrations of chemicals, and the tools of measurement. There were four points assigned to each component as given in Table 6.6.

Table 6.6: Rubric for evaluation of experimental design for indigo task

Descriptor	0 point	1 point	1 point	1 point	1 point
Parameters chosen for analysis	None	pH	COD	Suspended Solids	colour
Treatment chosen	None	for pH	for COD	for Suspended Solid	for colour
Executable plan (Feasibility in an undergraduate lab)	Not executable	Available time (3 lab sessions)	Available equipment	Available Chemicals /Substances	Available glassware
Quantities / Concentration	Not mentioned	Quantity of wastewater	Quantities for chosen treatment method	COD (Quantities of chemicals)	COD Concentrations of chemicals)
Optimization	None considered	Amount of AC/Saw dust/ Coagulant	Treatment condition pH/ temperature	Time for equilibration of AC/saw dust/ or coagulant	Minimally two trials
Flow-chart	Not presented	pre- treatment Analysis	Treatment after initial analysis	Post- treatment analysis	Clarity of representation
Tools for Measurement	None indicated	pH meter /pH paper	Glassware and indicator for COD	Weighing balance	Colorimeter / visual comparison

Since the task involved the analysis of wastewater, it was expected that the students select the four important parameters as mentioned in Table 6.6 and the corresponding treatment plan is suggested keeping in mind the feasibility of the treatment methods for execution in the undergraduate lab. Further, the optimization of the variables chosen was the module objectives given to them and thus whether it was included in the plan needed to be assessed. Drawing the flow chart suggests their ability to sequence the task logically and thus needed to be assessed through the rubric. Quantities and concentrations of chemicals become an inherent part of the conduct of experiments in a chemical lab. Likewise, the tool of measurement is an integral part of the experimental design of any lab investigation.

6.4.1 Reliability

Krippendorff, 2004 defines reliability as the degree to which the experts agree on the given text or data. The rubric for the indigo task was reviewed by two experts (Table 6.4). As part of the reliability exercise for use of the rubric, one of the students' EDs was jointly evaluated by reviewers and the researcher. Further, the Cronbach alpha (correlation coefficient) was determined to check how consistently the rubric is applied for evaluating the EDs by the experts, using the Real Statistics Resource Pack software (Release 7.6). A value of alpha of 0.7 indicates acceptable reliability and 0.8 or higher indicates good reliability (DeVellis, 2005,Taber, 2018). The inter-evaluator consistency for the ED scores by the two evaluators was found to be high (Cronbach alpha = 0.93).

The following section presents the methods for evaluating individual scaffolds.

6.5 Methods for evaluating individual scaffolds

Scaffold-1 : The precursor task

It was a simpler task relatively and needed only three steps to be evaluated. A rubric was developed and validated by the two experts. Table 6.7 describes the rubric in detail. The two parameters included in the rubric is logical steps and procedural details of the ED for the precursor task. The total possible score was six points if all three points under logical steps and procedure were included in the response by students.

Table 6.7: Rubric for vinegar ED assessment

Description	Points, for choosing three components	Points for choosing two components	Point for choosing one component	Remarks
Logical sequence of steps • Titrations • Molar calculations* • Trials with three different samples**	3	2	1	*Indicates conversion of molarity to %strength (m/V) **Three vinegar samples
Procedure • Clear • Correct • Glassware mentioned	3	2	1	

The inter-evaluator consistency between the two evaluators who evaluated the numerical scores EDs of the precursor task was found to be high (Cronbach alpha = 0.88).

Scaffold-2: The Reading Material

The reading material had the instruction to highlight the following information, i) information that discusses theory/concept related to the task, ii) important information that is needed for planning the laboratory work, iii) useful background information related to the task, iv) already known information and, v)information that needs further reading. The purpose of introducing these pointers was to understand the level of students' engagement with the reading material. Pointers, i) to iii) were important for designing ED in the indigo task. The pointers iv) and v) mentioned above were provided to help students in their metacognitive understanding and were not considered for analysis. In other words, these pointers provided clues to select the information that would be directly useful for planning the task, versus the information for building background concepts. The analysis included counting the number of responses received from each small group with respect to, a) the concepts/theory, b) parameters of analysis, c) treatment methods, d) effluent discharge limits, falling under the pointers i) to iii) mentioned above. Two evaluators were assessing the reading materials. The percentage agreement was calculated to be 83%.

Scaffold -3: Structured Group Discussion

For each workshop, the duration of the group discussion was for about an hour. The discussion was audio-recorded and transcribed. Codes were developed inductively after the data was collected to look for evidence of reflective thinking. Two pairs of coders analyzed the transcripts based on developed codes. There were four coders with varied experience levels in teaching undergraduate students. They were paired for carrying out the exercise of coding. Two coders as a pair coded the transcripts. The inter-coder percentage agreement between these two pairs of coders was checked.

The codes were developed by the researcher and were described to the coders. As a reliability exercise, a part of the transcript was coded together with the researcher. MAXQDA 2020 software was used for the qualitative analysis of group discussions. After two rounds, negotiated agreement of 83% was achieved between the two pairs of coders. The categories and codes used for the analysis of audio transcripts are given in Table 6.8

Table 6.8: Categories and codes

Categories	Codes	Explanation
Students' Statements	Explanation / reasoning	Reason for why the student is suggesting / narrating something
	Suggestions / personal views	Opinions/statements that do not refer to any resource or are not supported by a reason
	Acknowledge flaw/doubt	To accept or suggest some mistake/problem/inadequacy or express uncertainty in their ideas
	Agreement / disagreement	To agree or disagree with the other student's viewpoint
	Process / procedure / concepts	To describe plans related to the wastewater treatment
	Comparison	To judge which process, procedure, materials, chemicals, etc. may be better for selection
Students' Questions	Seeking explanation/elaboration	To know the other student's reasoning, response to these questions would need extra information than what is previously stated
	Seeking clarification	To understand better the other student's idea. Can be answered by, • repeating what was said • agreeing (yes) • without adding extra information

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As a part of the study, a questionnaire (Appendix K) was developed to understand students' perceptions regarding the scaffolds, the PBL task, and the group interaction. The following section presents a rationale for including this questionnaire as a part of the data collection.

6.6 Students' perception questionnaire

To triangulate the results obtained from the analysis of data (such as EDs, responses in task sheets, audio transcripts), it is important to gather students' perceptions that elucidate students' experiences. Participants' perceptions in the form of self-reports present diverse evidence of their own experiences when undergoing a particular cognitive phenomenon. In qualitative studies, student perception is considered one of the important methods for data generation. Students' perceptions are based on the complete experience and provide insight into what they have achieved (Berger, 2015; Eddles-Hirsch, 2015). Domin, 2007 reports the following as the strength of capturing such data.

- *"The perceptions of all the students participating in the self-reports can be pooled.*
- *What the student perceives may be of more significance than what an outsider would observe.*
- *Student perception data can be analyzed to provide information about the perceptions of different students within the same class."*

Students' perceptions can be captured through interviews, self-reporting, the Likert scale, questionnaires, rank order questionnaires etc. (Russell and Weaver, 2008).

In this study, a student perception questionnaire was developed to understand how they perceived the importance of the scaffolds provided to them. This was done through multiple sets of questions which included a rank order question, and a Likert scale question. Students had to express their choice of scaffolds in the order of the usefulness. There was also an open-ended question to understand whether there was anything other than the scaffolds provided to them as useful. The choices were coded and the frequency of the code was counted.

Additionally, the questionnaire also tried to capture students' perceptions of the difficulty level of the task and the group work. The questionnaire is in Appendix K.

Students' perception of working in a team was captured through the questionnaire as well as a semistructured interview. Written and verbal consent were sought from the students. The audio recordings of the discussions were transcribed.

6.7 Observer's note

Since the researcher was also the facilitator, it was deemed necessary to invite two external observers to avoid researcher bias in writing the field notes. Both the observers were introduced to the entire PBL module and were requested to note their observations on the interactions of the students for devising the experimental design. The observation of students' lab work was also noted down by the observers. One of the two observers closely followed one team specifically to note down how the group dynamics worked in problem-solving.

Thus, the methods to evaluate students' responses through ED, scaffolds, perception questionnaire, and observers' notes were devised to answer the research questions of Study 1. The measurement tools were validated and reliability aspects were determined. The methods followed to evaluate students' responses for Study-2 are described below.

6.8 Study 2: The impact of incremental levels of inquiry exposure on the science practice skills

The second study aimed at understanding the science practice skills acquired by students. This study required a descriptive detail of the science practice skills gathered by the students. The short course was implemented for four months and involved focused engagement with students during this period. Thus, a case-study approach was adopted as the research design for Study 2.

The case study approach helped to capture the student's ability with respect to science practice skills as the lab task was designed to be having incremental complexity in terms of the levels of inquiry. The case study conducted in an Authentic setting of students' home college makes the study "strong in reality".

Four different groups participated as a cohort in this case study which allowed us to capture the variation in the data. The study explored

a) students' response to incremental levels of inquiry,

b) the impact of incremental inquiry levels on science practice skills (hypothesis, results, and discussion).

c) usefulness of Laboratory Report Pointer (LRP) (Section 6.9.3) pointers to help students to generate written reports that communicate their investigation.

Thus, the research question explored through this case study was;

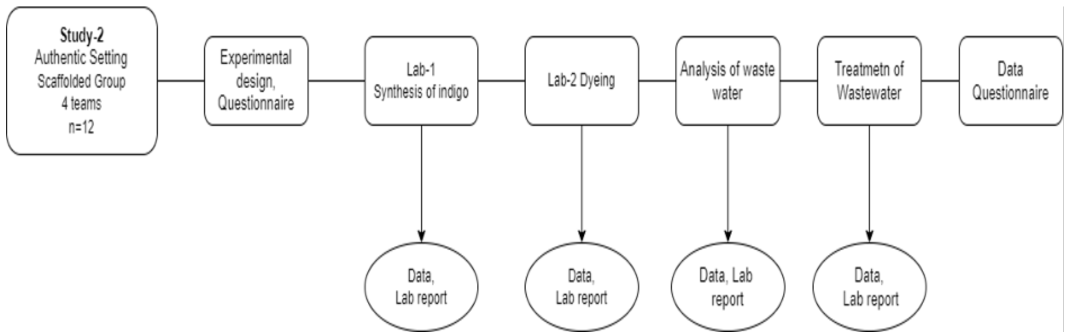
RQ-4. What does undergraduate students' chemistry lab report indicate about the science practice skills (hypothesis, data interpretation, discussion) acquired through incremental inquiry levels?

Students' lab reports were collected as data for each lab task (16 lab reports for four lab tasks). The reports were generated based on the LRP (described in Section 6.9.3) and were analyzed to understand the progression in the science practice skills acquired by the students.

6.9 Research design

The research design for this study is presented in Figure 6.2. The students were exposed to incremental levels of inquiry starting from lab-1 involving the synthesis of indigo dye. The lab reports were collected as data at the end of every experiment, for all four labs.

Figure 6.2: Research Design Study 2



6.9.1 Participants

A cohort of 12 first-year undergraduate students were the participants in our study. The prior academic achievement scores in the 12th-grade board examination of the students ranged from average to good scores (55 to 85 per cent). The participants had exposure to a semester-long general chemistry course and six months of exposure to the traditional laboratory course. Permission for conducting the course was sought from the college authorities and informed written consent was obtained from all the participants.

The protocols and background information were provided to the students in the reading material. Students performed the labs and generated the reports based on the pointers given to them (LRP). The following section describes the rubric for the LRP evaluation.

6.9.2 Method to evaluate LRP Reports

Detailed lab reports are one of the important components of laboratory experiments in communicating the scientific understanding generated through the investigation. A well-written report describes the interpretation of the investigation and thus, should be a carefully constructed document. Teaching students to write the laboratory report helps them share their results and reflect on the entire investigation process. Reflective writing of the lab report itself may promote inquiry and knowledge assimilation.

Inquiry laboratory differs from the conventional laboratory in aspects such as student-generated procedures, data collection and interpretation etc. driven more by students' self-directed learning. Thus, in the inquiry-based labs, the template given to students for reporting the investigation should be carefully crafted giving flexibility to the students. Table 6.9 presents a comparison of different templates prescribed for lab report writing in an inquiry and conventional laboratory. It also presents a comparison of LRP that was given to students participating in the case study.

Table 6.9: Laboratory report templates from CER.

Traditional lab report pointers (Greenbowe et al., 2007)	Traditional lab report (Lab manuals Manali publication)	SWH template questions (Burke et al., 2006)	Purdue Library recommendation (Library Guides at Purdue University Libraries)	Lab report prompts (LRP) for indigo course (Design by researcher)
Title	Aim	What are my questions?	Abstract	Aim
Purpose	Chemicals required	What did I do?	Introduction	Materials
Procedure	Apparatus required	What can I claim?	Materials and Methods	Theory
Data	Theory	How do I know?	Results	Research Questions/hypothesis
Result	Procedure	Why I am making these claims?	Discussion	Procedure
Conclusion	Result	How do my ideas compare with others' ideas?	Conclusion	Qualitative Observation
NA	NA	How have my ideas changed?	NA	Quantitative Observation
NA	NA	NA	NA	Results
NA	NA	NA	NA	Discussion

6.9.3 LRP report

The SWH template presents questions as prompts whereas the format recommended by Purdue goes close to the structure of a journal paper. In the Indian context, lab manuals of the traditional lab have all the necessary details. The students reproduce the given information in the lab journal. The LRP prompts in this study were a combination of prompts for the traditional lab and those provided for the inquiry lab. Aspects such as the aim, theory, and chemicals are selected from the traditional lab report pointers whereas the hypothesis, data collection, results and discussions are selected from the inquiry lab reports. The prompts from the traditional lab provide the direction to start their work whereas the prompts from the inquiry lab help students express their inquiry investigation. Additionally, for the researcher, it helped in getting the written responses to evaluate the science practice skills.

6.9.4 Rubric for assessment of LRP report

A rubric (Appendix J) was created for the assessment of the desired learning outcome namely science practice skills which include, testable hypotheses, EDs/procedures, data, and discussion. The maximum possible score in the rubric was 15 points for writing the brief theory of the experiment, hypothesis, flow chart/experimental procedure, qualitative and quantitative data, results, and discussion (Table 6.10). This rubric was validated by two experts (Table 6.4).

Table 6.10: Rubric for assessment of LRP report

Description	Subcomponent	Maximum Score
Overall lab report	• aim and theory • hypothesis, procedure/flowchart • data • discussion	15
Testable Hypothesis	• inclusion of variables • expected result • a plausible reason for the expected result	3
Procedure / experimental design	• preparation of reagents and solutions • logically sequenced steps • mention of independent variables • flow chart	5
Data	• qualitative data • quantitative data	2
Discussion	• connection of the results with the hypothesis • providing evidence from the data • offering a possible explanation for the observed results	3

6.10 Summary

This chapter described the methods to answer the research questions for both studies. The tools were developed and validated by experts and checked for reliability. For answering the research questions for Study 1 which explored the role of scaffolds, four workshops were planned and conducted for data collection. Participants' equivalence for these workshops was established through relevant statistical tests.

The experts were invited for validating the PBL module and the rubrics. Rubrics for evaluating the scaffolds, EDs, and lab reports were developed and expert validation was obtained. Codes were developed and validated for analyzing the group discussion. inter-rater reliability was sought for ED scores by evaluators. For Study 2 on the implementation of the short lab course, the experts validated the rubric developed for the evaluation of lab reports. The next chapter presents the details of Study 1 and the data analysis.

Chapter 7

Study 1: Role of scaffolds on experimental design

7.1 Overview of the chapter

This chapter discusses the implementation of Research Study 1 and its data analysis. The first research question explored the role of scaffolds (precursor task, reading material, and structured group discussion) in helping students in devising experimental design (ED). The second question explored how scaffolds helped students to move through Kolb's Experiential Learning cycle. The third question explored students' perceptions of working in groups. The data for Study 1 included EDs of the precursor task, annotated reading material, EDs of the main indigo task, audio transcripts of structured group discussion and students' perception questionnaire responses. The data were analyzed qualitatively to understand the impact of scaffolds on ED quality. This chapter presents the analysis of data collected to answer the three research questions mentioned above. The following section presents the implementation of the indigo module for data collection.

7.2 Implementation of PBL module for data collection

Study 1 was conducted both in Institute setting and Authentic setting (Chapter 6, Section 6.2.2). During the prelab work (first 2 days, 8 hours) students engaged with – a) Scaffold-1, precursor task (Appendix E), b) Scaffold-2, the reading material (Appendix F). and c) Scaffold 3, the structured group discussion.

The prelab data included the ED and flow charts of planning of, a) the precursor (vinegar) task and b) the indigo task. These EDs were from the scaffolded and unscaffolded groups of both Institute and Authentic setting. From the scaffolded groups in the Institute setting, the EDs for the indigo task were collected twice; at the end of first two scaffolds and once again after the third scaffolds. All the EDs were evaluated for their quality.

The reading material highlighted by students (scaffolded groups) was also collected as data. The annotated reading material was used as data to understand whether students selected the required information needed for the design of the indigo task. After the teams devised their initial plans, they had to present them to the rest of the teams during the structured group discussion. This discussion was planned to seek validation and input from other teams. Audio transcripts of these discussions were used as the data. Codes were generated to understand the nature of students' statements and questions as explained in Table 6.8. The frequency of the codes was counted and the students' statements indicative of the reflective thinking and co-construction of knowledge were identified.

After finalizing the EDs, students of scaffolded groups implemented them in the lab to collect data for interpretation and reporting of their investigation. This research study primarily analyzed the data from the prelab as the focus was to study the impact of scaffolds on the experimental design (EDs).

Since the research questions needed analysis of the prelab work, data from lab work was not analyzed. However, there were observers who recorded their observations as elaborate field notes in the Institute setting. Observer's notes are discussed in Section 7.6 of this chapter as they give useful insights about both these phases.

During the post-lab, students interpreted their data and reported the lab investigation. The questionnaire (Appendix J) responses were used to capture students' perceptions of the PBL module and the scaffolds. These responses were analyzed qualitatively.

The statistical tests conducted to establish the equivalence of the groups are discussed in Chapter 6 (Section 6.2.3). The following section describes the results of the analysis of data,

From Institute setting

i) EDs of scaffolded (SG) and un-scaffolded (USG) groups.

ii) EDs after two scaffolds and after the third scaffold.

From Institute and Authentic settings

i) Trends for EDs of the scaffolded groups,

ii) Students' perception of the scaffolds,

iii) Individual scaffolds (precursor task, reading material, and group discussion) in the Authentic setting,

iv) The external observers' reports of the lab work.

The inter-evaluator consistency between the scores by the two external evaluators who evaluated the EDs of the precursor task was found to be high (Cronbach alpha = 0.88) (DeVellis, 2005; Jonsson and Svingby, 2007). The same was also observed for the indigo ED scores (Cronbach alpha = 0.93).

7.3 Results and discussion

7.3.1 Institute setting

When compared, the mean scores of EDs for the un-scaffolded (6 out of 28) and scaffolded groups (17 out of 28) in the institute setting were different. The EDs of the un-scaffolded and scaffolded groups differed in terms of providing a feasible design with respect to the availability of time, chemicals, and equipment in undergraduate labs. The other difference was in the sequencing of the steps of the task. The following section gives examples of such descriptions in EDs.

7.3.2 Experimental design of teams from the un-scaffolded group

The teams in the un-scaffolded group provided only a treatment method based on the information perhaps obtained through browsing the internet. No team in the un-scaffolded group included sequencing of wastewater analysis pre-and post-treatment. Three teams (out of six) provided an infeasible design. The EDs of the remaining three teams were feasible but did not meet the module objectives. Most ideas were interesting, but no ED could have been executed in the lab. Table 7.1 gives an example of feasible and infeasible EDs by un-scaffolded teams. The ED presented in Table 7.1 by Team A2 is feasible. However, the module objectives are not met by this design. The phytoremediation suggested by Team A4 in this table is infeasible in the given time period because it would require that the students grow and test the suitability of the plant to treat the given wastewater.

The EDs by the un-scaffolded group indicated that providing only the problem statement was closer to open inquiry, requiring more time for a concrete understanding of experimental design.

Table 7.1: Example of Feasible and infeasible experimental design by an un-scaffolded team

Description	Example	
Feasible design Team A-2, Score=6/28	This problem could potentially be solved by satisfying the COD by oxidizing the substrates before their disposal. A favourable green oxidizing agent would be hydrogen peroxide, which is itself reduced to water. The sulphate salt, already at the apex of the latimer diagram, is unaffected by the addition of hydrogen peroxide, but the sulfite and thiosulfate ions face oxidation, giving sulfate ions.	
Infeasible Design Team A-4, Score=8/28	Process	Reason
	Wastewater	*Indigo wastewater with a larger number of debris, pebbles, mesh-like structure, and many organic and inorganic substances with indigo pigment.*
	Series of filters to remove larger particles	Larger pebbles, insoluble materials, and mesh-like structures are essentially removed
	Phytoremediation to reduce BOD and COD, some pigments, minerals/metal ions	Many inorganic (most of) ions and organic compounds which are essential for minerals nutrition of plants are taken up by the roots (essentially water is also consumed which meets the water requirement of the plant) plant used: Canna indica.
	Clean coloured water to a separate unit	Indigo dye which is now the leftover constituent is taken up by the hairs (wig).
	Dye water to use to dye hair which retains a large amount of colour and uses up extra indigo dye in the wastewater	# Artificial synthetic wig production(commercial process) maybe by soaking or providing mechanical stress to the hair on leftover indigo water.”

Further, the difficulties mentioned by students of the un-scaffolded group in a written response to a question in the questionnaire were –a) difficulty in understanding the online information, b) insufficient accessible information to plan, c) time-consuming, and d) difficulty in accessing the restricted articles. The inference is that comprehending the online content for application in a specific situation and designing the task within the stipulated time is cognitively demanding. Thus, students need a scaffold in the form of reading material to make the fact and information available readily.

7.3.3 Experimental designs by teams in the scaffolded group

The teams in the scaffolded group could sequence the task to analyze the wastewater before and after the chosen treatment (Table 7.2). This sequencing is essential to understand the efficacy of the proposed treatment.

Table 7.2: Experimental design by a team in the scaffolded team

<table>
<tr><th>Description</th><th>Example</th></tr>
<tr><td>Scaffolded team
Team C-2,
Score =19/28</td><td>1. “10 mL of sample: Filter the sample, pH, color of the sample
• 10 mL of sample: COD (filtration for obtaining COD). (Process -2)
• COD:
– 100 ml of $K_2Cr_2O_7$, 0.693 g in 100 mL
– (250 mL of) 0.25 M FAS (Ferrous Ammonium Sulphate), 2.45 g in 25 mL of DW
(Distilled Water), 5 mL Conc. H_2SO_4
• Conduct a blank titration of $K_2Cr_2O_7$ and FAS
• 10ml of sample + 5ml of $K_2Cr_2O_7$ + 15ml of Ag_2SO_4, H_2SO_4
– Add to the flask and reflux
– Add ferroin indicator and titrate with FAS
• Calculate the COD
2. 20ml (10ml (COD) and 10ml: Filter, pH, color) of the sample treated with activated charcoal
3. Repeat process 2) with chemical coagulation
4. COD value in 2) and 3) subtract from the original COD value and obtain the percentage of the organic matter that has been treated.”</td></tr>
</table>

The ED in the example presented in Table 7.2 describes all the steps. It included the quantities, concentrations of the chemicals, and the optimization process. However, some of the components included in the rubric for assessment, such as the tools for measurement, were missing. Thus, the presence of scaffolds has been useful for designing the EDs for the indigo task.

Further, the analysis of EDs was collected after two scaffolds and after the third scaffold was carried out for the scaffolded group. This analysis helped to know whether the reading material was sufficient for generating the EDs for the indigo task or whether the structured group discussion added value to the EDs. The following section presents a discussion about such a comparison.

7.3.4 EDs with two versus three scaffolds

Analysis of EDs suggests that seven teams out of nine included the quantities of various chemicals and optimizations of the treatment process (one of the module objectives) in their EDs only after the third scaffold. Table 7.3 presents the design of a team after giving two and three scaffolds, respectively.

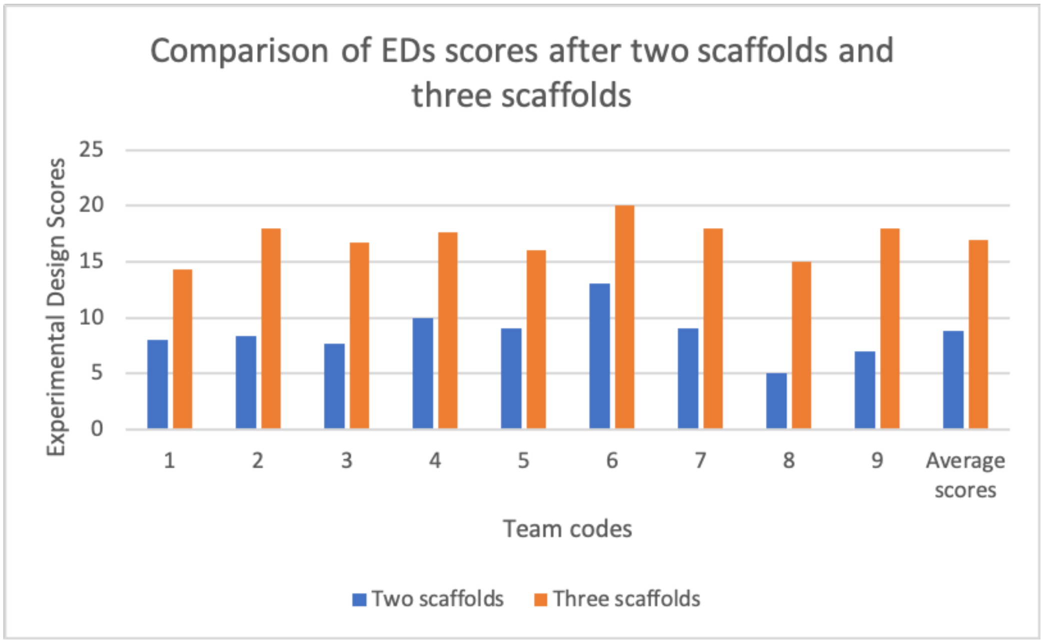
Table 7.3: Experimental design by a team with two and three scaffolds.

Description	Example
Two scaffolds Team-B1 Score =8/28	"Step 1 To the wastewater sample containing indigo white (whose COD is known), we add small amount of (estimated) of cellulose. Step 2: We allow the cellulose bonded to indigo white to settle as precipitate. Step 3: We then carry out separation of cellulose wastewater by filtration. Step 4:We then measure the COD of the wastewater. Step 5: Depending on the change in COD, further cellulose is added and/or reused in an estimated quantity. Step 6: The process is repeated in this fashion till significant reduction in COD is observed."
Three scaffolds Team-B1 Score =17/28	"COD of the sample is measured by the standard procedure. To 10 mL of the sample arbitrarily small amount of cellulose is added. The sample is stirred and then allowed to stay. Cellulose settles, followed by which filtration is carried out. COD of the filtrate is measured. Decrease in the COD is noted and depending on the change, the process is repeated. a) with different amount of cellulose at the same temperature. b) with the same amount of cellulose at different temperatures. If COD increases, the process is repeated at higher temperature."

The scores of EDs of Team-B1 indicated that group discussion as a third scaffold contributed towards improved EDs.

The mean scores for EDs after two scaffolds and three scaffolds were 9 and 17, respectively. Figure 7.1 presents improvement in the scores of each team after two and three scaffolds.

Figure 7.1: ED scores with two and three scaffolds



Further comparison of the results obtained in the Institute setting with the Authentic setting of students' college is presented in the following section.

7.3.5 Trends in EDs: the Institute and the Authentic setting

Students in the Authentic setting were given all the scaffolds since results from the Institute setting indicated that EDs that arrived at the end of the three scaffolds are qualitatively superior.

The EDs by the teams in the two settings were analyzed for the presence of three essential components of the ED, namely, a) the feasibility of the design for execution in undergraduate laboratories, b) the analysis of wastewater prior to and after the treatment, and c) the optimization of the treatment method or treatment conditions such as pH, temperature, and quantities. The number of teams in Authentic and Institute settings that included these components in their EDs was counted. Table 7.4 presents the results of this analysis.

Table 7.4: Components of the experimental design included by teams.

Components included by teams in the experimental design	No. of teams, Authentic setting Total=10 teams	No. of teams, Institute setting Total=9 teams
Feasibility of the design for execution in an undergraduate lab	10 (100%)	9 (100%)
Wastewater analysis pre and post the treatment	8 (80%)	9 (100%)
Optimization of the treatment process/condition	6 (60%)	7 (78%)

The number of teams that included these components in their EDs was almost identical in the two settings. All the teams gave a feasible plan, but some teams missed optimization in both settings. The audio transcript of the group discussion indicated that the teams were pondering whether they had to consider the most optimal treatment method or the optimum conditions within a method, such as pH and temperature. Possibly, understanding the term optimization was unclear for some students in both settings.

Further, to understand the trend in ED scores in the two settings, the range of scores where the maximum number of teams lay was identified. Figure 7.2 gives this comparison.

Figure 7.2: The experimental design scores of teams in the Authentic and Institute setting

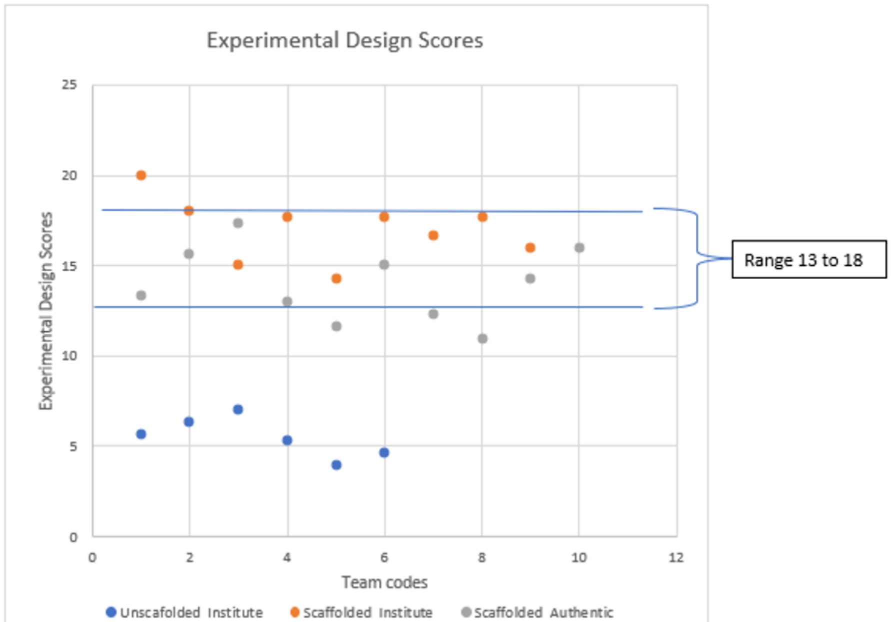


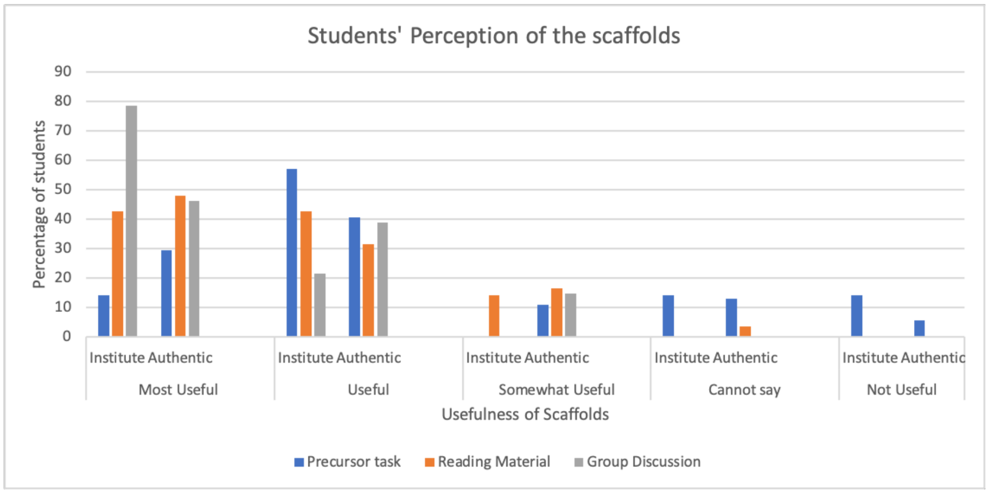
Figure 7.2 suggests that most teams had ED scores between 13-18 in both settings (Institute and Authentic). The mean scores of the Institute and Authentic settings were 17 and 14, respectively. However, no team scored a full 28 because no team included the tools of measurement in their EDs.

Thus, it can be inferred that the qualitative and quantitative trends in the experimental design of the scaffolded PBL are similar in both settings. A larger difference was anticipated due to the significantly different prior academic achievement scores. It is surprising but encouraging that the participants in the Authentic setting scored similarly to the Institute participants. It can be attributed to the fact that in both settings, the reading material constructed prior knowledge required for the task, and the EDs of the complex task were formulated with support from peers through structured group discussion.

7.3.6 Students' perception of the usefulness of the scaffolds

A five-point Likert scale questionnaire was given to individual students in both settings. Figure 7.3 presents the analysis of this data.

Figure 7.3: Students' perception of the usefulness of the scaffolds



The results suggest that most students in both settings considered all three scaffolds either useful or most useful. A small number of students were not as enthusiastic about the precursor (vinegar) task. The future study can explore whether all students are able to extrapolate the learning outcomes of the precursor task to the main PBL (indigo) task. It further explored how each one of the scaffolds helped the teams in EDs and whether the purpose of the scaffolds was met. The next section presents the results of this analysis.

7.4 Role of individual scaffolds

7.4.1 Precursor task

The number of teams scoring in different score ranges was counted in the Authentic setting. Table 7.5 presents an example of the result of this analysis. Seven teams scored either five or six (maximum score) on their EDs for this task. Such performance is most likely due to

Table 7.5: Experimental designs and score range of precursor task

Score Range Max. score=6	Teams in the given score range Max teams=10	Example experimental design from students' quote in the given range of score
Low (1 to 2)	0	——NA—-
Medium (3 to 4)	2	*"Identification of concentration of acetic acid in various types of vinegar* *By titrating above-mentioned types of vinegar against NaOH and phenolphthalein as indicator. It is a neutralization reaction.* *Different concentrations of a single type of vinegar can be tested for the same kind of pickle to now the exact concentration of vinegar, best suitable as a preservative for that pickle, same with other two types of vinegar."* (Team code D3)
High (5 to 6)	7 teams	*"Wash all the required apparatus, rinse the burettes* *NaOH being a secondary standard substance, its normality should be calculated before using it as a titrant for the further experiment. Thus, we standardize NaOH by titrating against HCl (0.01M) using phenolphthalein as an indicator, the endpoint being pink to colourless.* *After standardization of NaOH and calculating its normality and strength, we can use it as a titrant to test the concentration of acetic acid in each sample procured from the market.* *Now wash the apparatus, put NaOH (standardized) in burette-1 and put apple cider vinegar in burette-2. Calculate the normality of the solution and calculate its strength and concentration v/V.* *Repeat the procedure for other samples and compare the values to the required concentrations given for vinegar which is 5- 6%.* *The 5% , 6% v/V is converted to Normality which is 0.083-0.1N* *Phenolphthalein is used as an indicator and the endpoint is colourless to pink."* (Team code D8)

the familiar and easy content of the task. The inference is that the precursor task provided a concrete experience of planning an experimental design of a simple PBL task and helping them to move through the first stage of Kolb's ELC as was hypothesized.

7.4.2 Reading material

It was hypothesized that the pointers for highlighting in the reading material would help teams identify/select the necessary information for planning the task.

Six of 10 teams in the Authentic setting submitted the highlighted reading material which were assessed. Table 7.6 presents the number of teams that selected specific content from the reading material.

Table 7.6: Contents in the reading material selected by teams

Type of selected content	Number of teams that selected the contents, Max.=6 teams
The concepts/theory	5
Two parameters of analysis	4
Two treatment methods	4
Effluent discharge limits	2

Table 7.6 indicates that most teams, that submitted their highlighted reading material, could identify relevant concepts, but not all could select the expected number of parameters or treatments. To understand students' viewpoints about the content of the reading material, a 3-point Likert scale questionnaire (easy, moderately difficult, and challenging) was given. The following section describes this analysis.

7.4.3 Students' perception of the reading material

While the EDs were collected from the teams, responses to the perception questionnaire were collected individually from students. The analysis of questionnaire data of 30 students indicated that 17 of them found the content of the reading material easy to comprehend. Responding to another item in the questionnaire on the planning of the task based on the reading material, a large number of students (18) found it moderately difficult, and seven found it challenging. This result suggests that many students found the contents of the reading material easy to comprehend, however, synthesis of the content to develop an experimental design for the given task was difficult for the students. The content in the reading material was new to students and this may have added to the cognitive load, or possibly the content was cognitively less engaging.

7.4.4 Group discussion as a third scaffold

The audio transcript indicated various components of reflective thinking during the group discussion which are coded as given in Table 6.6. The following section provides an analysis of the audio transcript.

7.5 Reflective learning and collaborative knowledge building through structured group discussion

The discussion started with each team describing their plans. Three teams out of ten included only the plans while the others offered reasons for their choices. For example,
Student-D1:
"The third thing is about the color and we have to reduce the color, there are six methods given in the manual. For each method, the drawback is given in that itself. We are choosing activated carbon adsorption though it is expensive but is a comparatively very tricky manner to cover the color and remove color by 90%. And about 90% of the color is removed. The sixth method is also good like ultrafiltration. It is a physical procedure. We will be going with a chemical procedure."
Such a description of the initial plans was the basis for further discussion leading students to ask clarificatory questions. For example,
Student-D4:

"So, you are dividing the given sample, right? into different parts and each of them is treated in different ways and then you are comparing them and suggesting which one is better?"

The clarificatory questions may have helped students to compare implicitly or explicitly their plans with the ones that are stated by other students. However, the explanations offered by some students were not agreeable to others and that led to further questioning and reasoning. For example,

Student -D6:

"It is actually a great and easy method if you can actually confirm" (whether sawdust would work for vat dyes).

This process of negotiation continued till a consensus was reached between the presenting students' ideas and those of the others. This series of agreement, disagreement, and explanations improved the coherence and quality of the experimental design. For example,

Student-D9:

"After that, you add 4 gm per litre of i.e., 4 gm activated carbon per litre of the effluent you need to treat and leave them for 2.5 hours at room temperature... at 60 deg.C but at 2.5 hours in the room temperature, in the long run, it won't make a difference and after 2.5 hours, the coarse particles of activated carbon, we can actually remove the activated carbon can be filtered. We have the filtrate. Now the original wastewater you run a spectrophotometer on that at some frequency of close to 650 nm and ...once again you can note down the spectrophotometer and you can compare the two to find the effectiveness of the two."

Questioning peers or disagreement with peers not only led to sense-making as students articulated their ideas/thinking but also helped students see the flaws in the plans/ ideas. For example,

Student-D5:

"She has not specified the amount she is taking."

As the discussion progressed, students tended to evaluate their and others' plans. For example,

Student-D7:

"I like that they separated each step on the flow chart... it makes it clear, there are multiple procedures even though, each one is indicated in great detail, so I like that."

Seeking for explanation or clarification by students suggests they were perhaps engaging in reflective thinking. For example,

Student-D1:

"My question is, why are you using two methods: coagulation and activated carbon?"

Student-D8:

"Everything as in, what all will it adsorb; we have to make sure that every value lies under the tally,(discharge limits) right?" The student's quotes indicate that the structured group discussion provided an opportunity for reflective thinking.

The logic that went into designing the EDs was very different for each team and these varied perspectives became visible to many teams through the structured group discussion. Apart from getting clarity and rationale for the steps that had to be included in the EDs, students compared the flow chart of the precursor (vinegar) task with the indigo ED flowchart during the group discussion. This exercise led some students to identify the gaps in their EDs such as the quantities of chemicals.

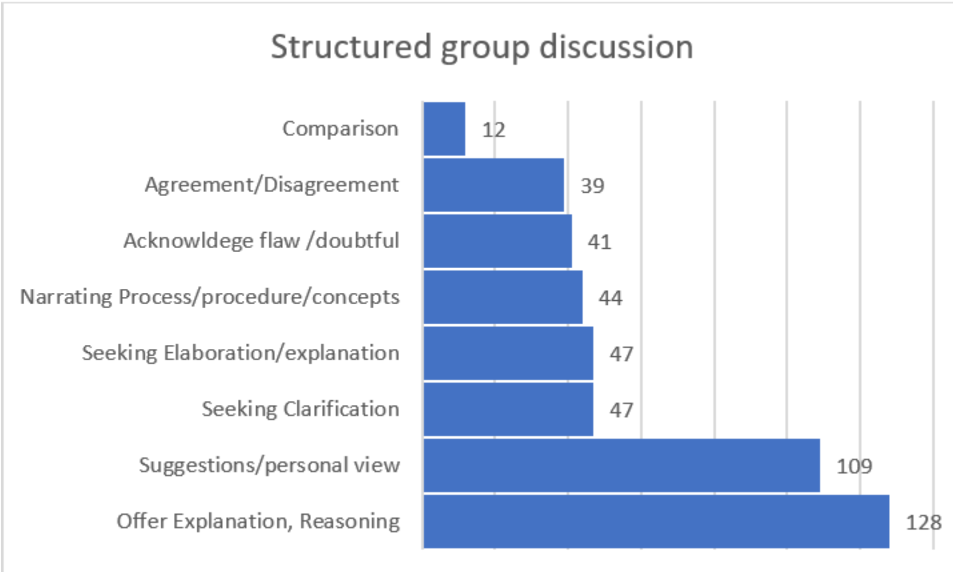
Since the designing of the experiment happened at the theoretical level, students got a chance to have their ideas validated by their peers while questions from peers probed the presenting students' thinking. For example,

"SS-1: So basically, you will be doing all of them?

SS-2: Not all of them.

SS-3: You have to do all of them. Because each of them comes at a different purpose. Chlorination is for disinfecting or killing bacteria, activated carbon is for adsorption and coagulation is mostly for the dyes, these two will result in colourless water. This can be done as a last process because this will be disinfecting, which will kill of the bacteria, each

Figure 7.4: Frequency of the codes in the transcript



of them serves a different purpose, you want to make sure.

SS-1: This is just for clarification, you are basically going to do all of them one by one, how strong the effects are and then decide which order to move.

SS-2: What is the effect on the economics of the situation?

SS-3: That is why we are first testing on the samples.

Thus, such reflective thinking might have contributed to an improved score of the EDs after the group discussion.

Further, the frequency of the codes in the group discussion were analyzed. Figure 7.4 indicates that students' explanations and reasoning are the most frequent code in structured group discussions. The substantial number of students' questions (Figure 7.4), seeking an explanation and clarification, may have contributed to the student's reflection on their initial experimental design while presenting the ED. This activity may have led to improved EDs.

Each aspect of the group discussion mentioned in Figure 7.4 gives the opportunity to reflect on the adequacy/gaps of students' plans. Students need an opportunity to reflect on the connection between the content of the reading material and their experimental design. Structured group discussion provided the opportunity for the same.

Thus, it was inferred that structured group discussion supported reflective thinking when students justified their stance or revisited their ideas and improved the quality of the experimental design.

Since the researcher was facilitating the PBL module, it was considered useful to invite external observers to provide insights devoid of researcher bias. The observers prepared field notes for the prelab phase and also the lab work done by the students. The notes by the observers which corroborate the analysis of students' work are provided in the following section.

7.6 Observer's notes

For the Institute setting (workshop-1), an external observer (observer-1), an experienced chemistry teacher with more than 30 years of teaching experience was present and shared her notes for the prelab and lab work phase. For workshop-2, another observer (observer-2), a senior graduate student engaged in the development of inquiry-based instructional material observed one team closely during the prelab and lab-work phase. Observer -2 made detailed notes about this team and their work. The following section describes notes by both observers.

7.6.1 Notes by observer-1

Regarding the reading material and precursor task, observer-1 noted that,

"The handouts were extensive. The inclusion of the precursor was a big help. This gave the teams the feel of what is to be done to a large extent, however, the time taken to complete this part of the sequence was more than what was slotted.

The observer recommended that the length of the reading material can be reduced to make it more effective.

She further noted the following regarding prelab,

"All experimental plans were discussed thoroughly by all members before agreeing or disagreeing to execute them. At times there was a need of bringing the team (team) on track in terms of their plans, but at no stage was 'hand-holding' done.

About the experimental work she remarked, *"As for the 'experimental part' was concerned, a good attempt was made in the planning and execution. A couple of teams were keen on attempting treatment options that were not listed in the literature".*

However, she commented on the time management in the prelab and the lab phase. In her opinion, *"...better time management was required because the work for both these phases got extended beyond the prescribed time... There was a timeline identified for the sequence which was not followed hence time was required beyond the hours to complete the needs (eg. discussion continued beyond the time)"*

This observer also recorded that the interpretation of results could have been deeper as extensive data was collected by the students. Her remarks are given below.

She further remarked, *"Data obtained from the experimentation was a lot but the conclusions drawn from there did not give an impact. There could have been a little more reflection given to the data and this could have been collated and concluded in a stronger way."*

These remarks suggested that students required appropriate pointers to capture and collate the lab investigations done at their end meaningfully. This aspect was paid attention to and was integrated with Study 2.

7.7 Notes by observer-2

While following a team, observer 2 stated that students used their prior knowledge and applied it in the new context. Additionally, the observer opined that the availability of internet access helped students to explore further. The excerpt of notes by the observer indicating the same is given below.

"The group's plan was based on using cellulose (present in cotton) to bind to the indigo dye and remove it from the wastewater. To justify this idea, E1 explained the chemical structure of cellulose and how indigo and cellulose binding took place. In particular, he referred to the material provided on pages 4 and 5 of the reference document provided to the students... While terms like hydrogen bonding are present in the reference document, "trans bonds", "cellulose-indigo bonds" and "cellulose-cellulose bonds" are not present there. These have therefore originated from some external source or the students themselves."

According to this observer, the group discussion provided an opportunity to gain clarity and to look for alternative views. The paragraph below indicates this aspect.

"...Team E then discussed other peoples' ideas. During this time, further illustrations of their understanding of the problem situation were seen. For instance, E1 was able to point out to one of the teams that they had a misunderstanding about COD (chemical oxygen demand): COD should be used as a means of assessment, not as a means of treatment (as the team was suggesting).

Other questions raised during this discussion were about whether the dye would be collected back from the wastewater after it had been treated, to which E1 and E2 both replied that they were not concerned with recovering the dye."

"The team attempted to be trying to justify to themselves as to why their treatment was effective – why this treatment should be chosen over some other. A tacit assumption that the team seemed to have been operating with was:"the treatment method needs to have a strong theoretical underpinning / justification". This is an epistemic position taken by the team."

The prelab work involved gathering an understanding of, what has to be done and why it has to be done, which is crucial for the PBL environment. However, students at this stage had a hazy idea regarding the conduct of the lab work. According to observer-2, such an understanding was generated when students started taking trials in the lab. The excerpt for the same from the observer notes is given below.

In lab, E2 was tasked with treating the dye with cellulose. However, he appeared to be unsure of himself in the lab, and about using the various lab equipment. The pipette used in the lab was different from the one that he was used to previously, and this made him more anxious about his actions. E2 had to measure out an initial mass of sawdust to add to the wastewater. He approached me with the question that although he knew he had to take some arbitrary number, he did not know what that number should be.

He then began stirring it, but mentioned to me that he did not think it would work, because there was no colour change. E2's plan was to continue stirring the sawdust in the wastewater, and at some stage to filter it out and test the COD of the filtrate. However, when I asked him at what stage he would move to filter the solution, he seemed unsure and did not respond. E2 decided to test a second sample in which he would add more sawdust. He was initially thinking of adding 0.16 g of sawdust (increasing by 0.1 g);

E1 had been working to prepare the solution for the measurement of COD. To do so, he had been following the procedure described in the reference document. However, he had some doubts about calculating the number of reagents required to prepare the solutions of the appropriate concentration. He asked the instructor for assistance and got into a debate about whether to use molarity (M) or normality (N) when calculating solution concentrations. This became a whole class debate. While E1 felt that normality was appropriate, the instructor recommended using molarity for such measurements.

When E1 returned to measuring out the reagents, I conversed with him. For one, he appeared to be thinking about a number of things. He commented that the other teams were working with potassium permanganate and that it had caused the colour of the solution to change, and E1 also mentioned that he felt under time pressure to get things done. He had realised that the process of measuring COD was quite time-consuming (requiring an hour for reflux, and then some more time to cool before titration could be done). As such, he felt that the team needed to move fast and could "not afford to be wrong". In this context, *he also mentioned that he had "made a blunder" in preparing an insufficient amount of standard FAS (ferrous ammonium sulphate) solution. Thought, they had removed the dye, but they were wrong.*

The above description may give a perception that the lab experience was frustrating for E1. However, such experience provided an opportunity to continue thinking thereby to resolve the difficulties/errors/confusion etc.

The free time beyond the lab work provided an opportunity to reflect back, discuss with peers, and find more resources for clarification. Such engagement beyond the lab session led to a better approach to the investigation on the subsequent day. The evidence for this process was seen through the following note by the observer.

While the team had some confusion about how COD was to be measured, they managed to resolve it. At the end of the day, they had managed to prepare the apparatus to measure COD and had begun measurement of the COD of the pre-treatment sample of wastewater. A number of interesting changes were seen in the students' attitudes on this day. For one, it was clear that the students were far more familiar in the laboratory, and with the nature of the work that they were required to do. One outcome seemed to be that they were willing to investigate and test out a number of additional hypotheses. For instance, E2 tested the effect of leaving sawdust in the sample for 48 h, as well as the possibility that the colour change may have been due to the sawdust. In the latter case, he designed a simple control setup using water and sawdust to investigate his hypothesis. In addition to these, E2 in particular also seemed to have become more comfortable with the notion of qualitative data, as evidenced by his response to the debate about addition of liquid alum. During this debate, E2's statement "let us try it" is also instructive, as it suggests him acquiring an openness to observational data.

One of the important aspects of the laboratory learning experience is to provide students with the opportunity to modify their plans after encountering challenges and carry out trials a second time, especially in an inquiry investigation. The observer has noted that the students seem to have got better with ways of investigating after the first trial. An example of this aspect is given in the paragraph below.

Compared to Day 1, students were able to carry out a greater number of experiments. For example, students set up the reflux apparatus for COD measurements, but also tested addition of sawdust to plain water, compared colour of different samples (wastewater + 0.06 g sawdust, wastewater + 0.6 g sawdust, wastewater + alum), and acidified samples and measured their pH. I believe that this may be explained by two reasons. For one, students' familiarity with the laboratory apparatus and procedures may have contributed to their efficiency. In addition, the students seemed to be thinking about using their spare time in an optimal manner. For example, while the reflux was going on, E2 suggested that E1 use the time to prepare a standard solution of acetic acid.

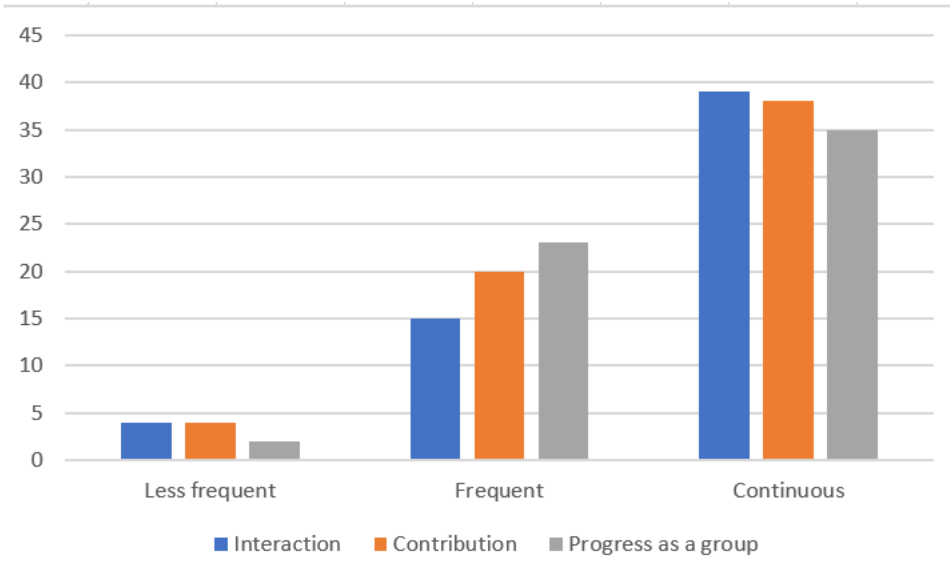
Thus, the observer noted a shift in the attitude on day-2 after students confronted the challenges on day 1. They became more comfortable/familiar with the lab and the lab work that led to multiple trials with variables.

The observer said students did not resort to available resources (reading material or the internet) to gather more information. The observer pointed out the following challenges in learning the process skills.

"... a) choices about how much cellulose (sawdust) to add for the treatment of the wastewater, b)how long to stir it for, and c) how to go about calculations. The students also had to contend with learning laboratory skills of using and setting up apparatus under time pressure. To me, it seems that these are noteworthy opportunities for teaching laboratory process skills and making students aware of the extended range of considerations that need to be accounted for in a good plan."

"... the students' notions about valid justification appeared to have shifted from that on Day 1. Whereas on Day 1, students focused on theoretical reasoning, on this day, it was evident that they were more committed to using evidence from experiments to justify their claims."

Figure 7.5: Students' perception of teamwork



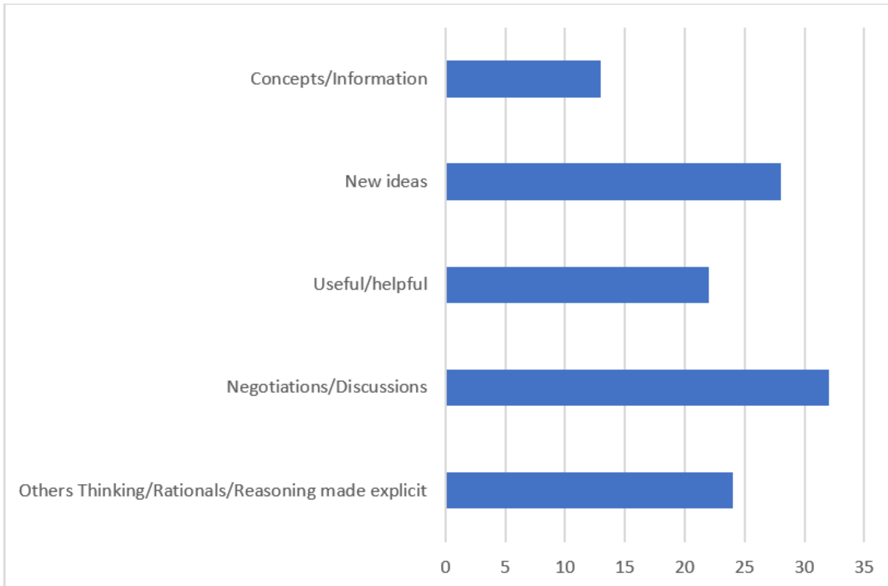
The detailed notes by two external observers suggested that the students got ample opportunity to go through the process of science. For example, during the prelab, the observer noted that the students went beyond devising a plan and discussed why sawdust would work, trying to hypothesize. The observer's notes helped to infer that the objective of the module, namely, to learn to design an experiment was achieved through the indigo lab. Thus, these field notes by observers corroborate the results from the analysis in this chapter. It also indicates the significance of the collaborative construction of knowledge through lab work regarding science practice skills.

7.7.1 Students' perception of the teamwork

The responses to the Likert scale questionnaire for understanding students' perceptions about their team are presented in Figure 7.5. The number of participants who responded to this survey questionnaire was 57 from all four trials.

The graph indicates that a large number of students (35) thought that there was continuous

Figure 7.6: Outcome of interaction



interaction among the members who contributed equally in progressing with the problem-solving. Up to 20 students felt that the interactions were frequent and less than five students thought the interactions were less frequent and not everybody contributed equally. Some students are not verbal when it comes to communicating. In some cases, if one of the members is dominating then there is a possibility that all members are not able to interact confidently. In a response to an open-ended question on experiences of interaction, students acknowledged that they got to understand the reasoning/thinking of the other members while the discussions were happening. Though many had found the discussion useful/helpful, a handful mentioned about the length of the discussion had got tedious. This result is presented in Figure 7.6. The following paragraphs present the analysis of the semi-structured interview of one team.

The students considered disagreements as both a hurdle and a way of moving forward with different ideas getting shared. However, two of the members also opined that the team should not be made through random selection rather the students who have similar ideas on the content of the work to be carried out should be pooled together. One of them acknowledged that there could be other kinds of diversity in the team, however, a dominating member of the team may hinder the progress of the work. Contrasting this viewpoint another member suggested that, *"... making team random is the way to compel students to develop skills they do not have... arithmetic of ideas is better in a team"*.

The third member of the team mentioned that new ideas are discussed and rationalized which one will work and which will not. The second member further clarified that working in a team is what he advocates and just that it should be homogenous in terms of the idea on which they want to work. When asked about the gender difference in the team, one of the members said, *"Certain level of courtesy is extended to whomever you are working with and I will not fail to extend that courtesy to an opposite gender interaction..."*

All three members agreed that mixed gender team is helpful and this is a way to reduce the distinction and reduce the disparity existing in the society".

Recognition of the strength of team members becomes important. Members of the team understand this aspect especially when they are working in a time-constrained environment. Team learning is a way to elicit good learning outcomes. Yet the facilitator needs to be conscious of various possible emotional and social factors that may hinder learning. The questionnaire data and interview data indicate that teamwork is successful when students need to generate newer ideas and rationalize their viewpoints, however, the team members with similar ideas to explore can progress faster than those who have some differences on the basic idea which need consensus from members before moving forward.

7.8 Summary

This chapter presented data analysis to explore three aspects, namely, the effect of scaffolds on EDs, the impact of individual scaffolds to help students move through the first three stages of Kolb's ELC and students' perception of working in a team. The analysis suggests that scaffolds were helpful to students in devising the ED and helped them to move through the three stages of Kolb's ELC. The structured group discussion helped students in gathering new ideas from one another and in expanding their thinking.

One of the strong reasons for the success of the scaffolds was the sequencing as per the stages of Kolb's ELC cycle. Students got concrete experience in devising ED for the precursor task. Since the contents and concepts associated with the precursor task were familiar, students could focus their attention on understanding what components need to be considered for devising the ED. The other concrete experience was in the construction of prior knowledge with the help of reading material. The structured group discussion was the most important scaffold that engaged students with the dialectic conversation for reflective thinking. The drawing of the process flowchart by students indicated that they moved to the third stage of abstract conceptualization (ED). Thus, the scaffolds contributed to the first three stages of Kolb's ELC for meaningful learning.

These scaffolds also helped in following the model proposed by Agustian and Seery, 2017 for scaffolding strategies for prelab work. The strategies that the scaffolds followed were the simple to complex task, and the whole task strategy.

Questionnaire responses indicated that the students found the group work useful in understanding concepts and various perspectives other than their own. This leads them to construct knowledge. Such collaborative knowledge building during group work is supported by the social constructivist theory. Students found group discussion as a way to overcome the challenge posed by the complex PBL task.

After understanding the role of scaffolds, the short course on indigo dye was implemented with a case study approach. The next chapter presents the discussion of data obtained from this implementation study in detail. (A large part of the work presented in this chapter is published by the researcher in Varadarajan and Ladage, 2022a).

Chapter 8

Study 2: Implementation of the short course on indigo

8.1 Overview of the chapter

This chapter presents the analysis of data on the implementation of the indigo short lab course. The focus of the analysis was on understanding the impact of incremental inquiry levels on science practice skills (hypothesis formulation, data collection and the discussion of their results). The study followed a case study research design.

8.2 Implementation of Study 2

The short course consisted of four experiments related to indigo dye. These were: i) synthesis of indigo dye, ii) dyeing of yarns using synthesised dye, iii) wastewater analysis, and iv) wastewater treatment. Students preserved the sample of wastewater generated during the first and second lab work to be used during the third and fourth labs. The protocols for carrying out the first and second labs were shared while students had to devise the experimental design for labs 3 and 4. Each lab has three components. prelab, lab and post-lab.

Table 8.1 gives the time distribution of these labs during the implementation of the short course.

Table 8.1: Time allocated for the prelab, lab and post-lab sessions

Description	Lab-1 Synthesis (hours)	Lab-2 Dyeing (hours)	Lab-3 Analysis of wastewater (hours)	Lab-4 Treatment of wastewater (hours)
Prelab	2	4	8 spread over two days	Combined with Lab-3
Lab	4	4	4	4
Postlab	1	1	1	1

Time allocation for prelab varied depending on the inquiry level. The prelab of lab-3 and 4 were combined because the experimental design (ED) at the end of the students had a sequence of waste water analysis$\rightarrow$ treatment$\rightarrow$ analysis.

The data collected in this study was LRP lab reports generated for each lab experiment. The number of students who participated in the study was 12. They have divided into 4 groups and each small group consisted of 3 students. 16 lab reports were obtained (4 groups and 4 lab experiments). Students were provided Lab report pointers (LRP) for generating lab reports which were a combination of pointers from the conventional labs and some pointers for inquiry labs. These pointers helped to capture the science practice skills of students as data.

8.3 Analysis of lab reports

The following section presents the analysis of the lab reports that describe the quality of the hypothesis, the data collected, its interpretation and discussion of the results. A rubric (Table 6.10) validated by experts was used for giving scores to the lab reports.

8.3.1 Identification of variables and formulating hypothesis

For lab task-1 (synthesis of the indigo), students identified the following variables for their investigation; a) the base (KOH vs NaOH), b) the rate of addition of sodium hydroxide dropwise addition vs all at once), and c) the concentration of sodium hydroxide for identification of the limiting reagent, and d) the volume of acetone (reagent). Out of the four groups, only one group did not include a hypothesis even though their lab report indicated that they investigated the effect of the chosen variable.

For the second task, students generated a list of variables affecting the dyeing intensity which included–a) type of yarn such as the bleached/unbleached, cotton and polyester yarns, b) the calculated percentage shade, (hypothesizing that the dye uptake by yarns may have a saturation point), c) the temperature of the dye bath, and d) the dipping time of the yarn. Each group chose to investigate one of these hypotheses. The analysis of the lab report indicated that all four groups had a full score of 3 for hypothesis writing. The group which missed writing the hypothesis in the first experiment also gave the hypothesis for this experiment. Table 8.2 compares the hypothesis between the first and the second experiment by group-3 as an example. Compared to the first task, a qualitative improvement in the hypothesis was noticed in all four groups from lab task-1 to lab task-2.

Table 8.2: Hypothesis for experiment-1 and-2 by group 3

Group-3	Hypotheses	Scores(max=3)
Exp.1 (Synthesis)	"Factors varied were: a) Volume of acetone (from 5 ml to 10 ml) b) Volume of acetone 10 ml, the concentration of sodium hydroxide is increased from 1M to 1.5 M."	1 (Expected result and plausible reason not mentioned)
Exp.-2 (Dyeing)	"Elevated/depressed temperature can affect indigo dyed yarn's physical appearance, particularly colour. With an increase in temperature, the colour intensity of the dye should be darker With an increase in temperature, the time taken by the dyed yarn to oxidize should be reduced."	3 (Variables, expected result, and reason mentioned)

Table 8.2 indicates that there is an improvement in the scores between the first and the second hypothesis stated by Group 3. The second hypothesis mentioned variables, expected results, and reason whereas the first hypothesis only suggested the variables. This improvement in the score was noticed for three out of the four groups which included all three aspects of the hypothesis namely, the variables, the expected result, and a plausible explanation. The group, which had not given any hypothesis for task -1, gave the variable and the expected result for the hypothesis framed for lab task-2, indicating improvement. Further, to understand whether the quality changed as the student groups moved from experiment 1 to 4, the hypotheses were tracked in all four experiments for each group (Table 8.3). The inference from the highlighted part of the text in the table is given in the following paragraphs

Table 8.3: Hypotheses by group-2 across all the experiments

Group-2	Hypotheses
Exp.-1 (Synthesis)	"NaOH is to be added dropwise in the reaction mixture. The hydroxide ions are involved in step-2 and step-4. We predict that if it is added over a greater time, the reaction will get completed properly and this might result in a darker colour. Adding the NaOH immediately might give lesser yield due to not all reactants being used completely."
Exp.-2 (Dyeing)	"The intensity of colour should increase with an increase in the concentration of the stock solution used... because an increase in the concentration of dye means that there will be more quantity of dye in a given volume of dye solution. Hence the material will be able to absorb more dye. There can be one possible scenario where the material has absorbed a certain maximum amount of dye after which, maybe, it won't be able to absorb any more of the dye and an increase in concentration will not show the same effect it did before i.e., for lower concentrations."
Exp.-3 (Analysis)	The indigo synthesis wastewater contains NaOH, acetone, o-nitro benzaldehyde, and indigo dye. Because of these compounds, we expect the wastewater to have a high COD. Question: Is indigo a reducing agent? Hypothesis: If so, it will have a high COD (greater than 10,000 at least) and will exceed the allowed limit for disposal. Also, the synthesized water will have a much higher COD than the dyeing wastewater. This is because vat dyeing involves the oxidation of the indigo dye.
Exp.-4 (Treatment)	The COD of the wastewater should decrease after treatment. The effectiveness of activated charcoal in the reduction of COD is hypothesized to increase with decreasing temperature based on the paper by Rajeev Jain et al., Journal of Scientific & Industrial Research, Vol. 65, March 2006. Hence, the COD for the sample that is kept in the refrigerator should turn out to be lesser than that of the sample kept at room temperature.

The hypothesis for the first task had simple statements with variables and expected results. The second hypothesis suggests that this group could think of the possibility of an alternate hypothesis and a rationale too for the alternative. Such a thought process prepares for acceptance or rejection of the hypothesis and suggests an open-minded approach to investigation. Further, the third hypothesis indicates how students connected this task with the first one. This indicates that the students did not view the task in isolation.

Further improvement is seen in the fourth hypothesis when the student group has gathered information from the literature and grounded their hypothesis on previous research. A comparison of these four hypotheses suggests a greater cognitive engagement with the increasing inquiry level. This trend in enhanced cognitive engagement was noticed in all four groups as they moved across the lab tasks involving a higher level of inquiry. Thus, it can be concluded that the student groups were successful in the formulation of better-quality hypotheses across tasks.

8.4 Analysis of lab work

The lab reports indicated that students had taken three trials of the variables and all the reports have both qualitative and quantitative data. Qualitative data were supported by photographs wherever deemed appropriate by the student group. After the lab work students also captured photographs of the dyed yarn to develop a measure for comparison of the shades of dyed yarn, one small group compared the dyeing quality through a mobile app for finding the RGB (red, green, blue) values of the yarns. They found the RGB values at multiple points of the photograph of their yarn and calculated the average for these values taken. Yet another group used the in-built colourimeter of their computer to determine the RGB values of the photographs of the yarns. Two of the remaining groups could not ideate a solution. The facilitator nudged them to arrange the yarns in the order of increasing shade intensity and then think of a solution. The students then chose yarn with the medium shade which was given a specific reference number and the rest of the shades were given numerical values relative to this reference. Possibly, this was a difficult task.

For lab-3 and 4, although the student groups had planned for the analysis of three parameters, except one, the other three groups could analyze only two parameters i.e., pH and COD.

8.5 Analysis of observations and results

The discussion sections were written by all the groups. 13 out of 16 reports, had a score of a full 3 points for this section, indicating that the students could connect the hypothesis to the result section and offered an explanation for their observations. The remaining three reports presented only the conclusions from the data.

Tables 8.4 and 8.5 present examples from four different groups. These examples exhibit varied ideas presented by various student groups.

Table 8.4: The discussion of the results by student groups 1 and 2

Groups	Exp.1, Results and Discussion	Exp.4, Results and Discussion
Grp-1	"The KOH leads to a higher yield than the NaOH by 0.171 x 10^{-4} mol. This amount is not particularly significant. The difference between the yields may have been caused by other smaller factors which are harder to regulate e.g. – minor errors when measuring reagents, the efficiency of stirring, etc. The experiment will need to be repeated in order to conclusively prove or disprove the hypothesis.	"The hydrochloric acid actually yielded a poorer result in terms of COD, contrary to our hypothesis which suggested that the hydrochloric acid would yield a lower COD than the acetic acid. A possible cause for this is that the side products formed by acetic acid have a lower COD than those caused by hydrochloric acid. Another reason for the much higher COD of sample A could be that the HCl reacted with the $AgSO_4$ and formed a precipitate of $AgCl_2$. This would have reduced the efficiency of the reflux, and thus made the measurement of the COD inaccurate. Overall, sample A can be considered fit for discharge into public sewage, and sample B, after further treatment for suspended solids can also be discharged into public sewage."
Grp-2	"The highest yield was when NaOH was immediately added to the reaction mixture. The colour of this dye though was not as dark as the others. . . . .The second highest yield was obtained from Dye no. (3) i.e the one in which NaOH was added over 10 minutes. The colour of this dye was the darkest of the three. . . . . . . The colour of the dyes matches our hypothesis. The yield of the dye clearly depends on other factors as well."	"The results did not turn out as expected. The COD of the sample which was treated at Room Temperature reduced more as compared to the one treated at a lower temperature. This, along with the observations of the paper (Rajeev Jain et al., Journal of Scientific & Industrial Research, Vol. 65, march 2006.) indicates that the effect of activated carbon increases with decreasing temperature up to a certain maximum after which, it may decrease or remain stable. Further experimentation is needed to understand the trend clearly."

Table 8.5: The discussion of the results by student groups 3 and 4

Groups	Exp.1, Results and Discussion	Exp.4, Results and Discussion
Grp-3	"... 2. Acetone used in comparatively greater quantity gives more yield. Observing the quantitative table for yield of indigo dye, we can conclude that acetone, when used in comparatively greater quantity gives better yield. Thus, we can say that acetone is the limiting reagent for indigo synthesis. ..."	"COD of both indigo synthesis and indigo dye waste waters have increased almost twice after their treatment with activated carbon. This might have happened as a result of dying bacterial cells. They decompose and release dissolved organic carbon (DOC) which in turn increases COD2)."
Grp-4	"The information from the quantitative observation table, we write the conclusion that more yield can be produced by taking the concentration of 1M NaOH for indigo dye synthesis."	"The pH of treated waste was found to be neutral after the treatment with activated charcoal. the pH of untreated wastewater was 12. After filtration, it is made neutral by adding drop by drop of acetic acid glacial. The COD for treated wastewater was found to be lower than untreated wastewater."

It can be inferred from tables 8.4 and 8.5 that all the groups formulated the results and discussion section as per the pointers in the rubric. Explanations offered by groups for experiment 4 (highlighted part) were interesting. For example, group 1 thought of two plausible explanations for their observation of experiment 4. Group 2 understood that their results contrasted with what the literature stated. They also understood the need to explore further before making a conclusive statement. Group 3 offered a biological explanation of the observed chemical phenomenon exhibiting an interdisciplinary perspective. Group 4 mentioned only the results. It needs more training/ exposure in formulating hypotheses as well as the result and discussion section. Such varied performance is expected in an academically diverse classroom. There was evidence for reflective thinking during group discussions. Table 8.6 presents the categories and examples of questions that prompted reflective thinking during the prelab phase.

8.6 Designing experiments

Regarding lab tasks 3 and 4, the audio transcripts of group discussion indicated that two groups relied on obtaining the required information through the internet as well as the reading material, for example, one group stated that the saw-dust mentioned in the reading material may be difficult to procure as the source needs to be a softwood for better adsorption. Further, they gave orange peel as an alternative to sawdust based on the information obtained by browsing the internet. They provided an advantage of this alternative stating that orange peel can be procured in large quantities for scaling up as it is a waste product from the juice industry. The other two groups relied on the reading material even though they had access to the internet. Thus, there were variations in the initial EDs of the student groups as expected.

The group discussion provided an opportunity for argumentation and construction of explanations for students' choices in the ED, helped students in reflective thinking, and to modify the initial EDs. Table 8.6 presents these ideas.

Table 8.6: Indicators of reflective thinking in group discussion

Indicators for reflective thinking	Example of questions from students
Seeking clarification of ideas	"S1: Where did NaOH come from in the wastewater? S2: NaOH is used to let the cloth absorb the whole dye, S1: It's not in the wastewater it's in the cloths as far as I know it doesn't same compound"
Seeking an explanation for the stated plan	"How did you find out that this treatment will work for indigo which is an azo dye because it (indigo) is not an azo dye?"
Acknowledge doubt/ flaw	"... because to be very honest we do not know, lot about treatment, So, we decided that we will divide the whole wastewater that is supposed to be treated and whatever method we find out we will apply on the sample and we actually check whether it resulted in a reduction in pollutants and constituents"
Agreement/disagreement	"S3: Bleaching powder instead of activated carbon, we can use. S4: The two have different properties, how does bleaching powder will absorb? S3: It won't absorb. It is for oxidation, bleaching is only relevant to the colour, and activated carbon also absorbs colourless pollutants. S4: Yeah"

Table 8.6 suggests that the questions, clarifications, and responses during the group discussion helped students to refine their plan to make it feasible for execution.

8.7 Overall scores for lab reports

Student groups presented the reports effectively utilizing the Lab Report Pointers. The scores for the report ranged from 12 to 15 (max. score 15) suggesting that most of the aspects of the rubric are included in the report for almost all the experiments by the groups (Table 8.7).

Table 8.7: The scores obtained by each group on the four different lab tasks

Groups	Synthesis (Exp.1)	Dyeing (Exp.2)	Analysis (Exp.3)	Treatment (Exp.4)
Group-1	15	14	12	15
Group-2	15	14	15	12
Group-3	15	15	9	13
Group-4	11	15	12	14

The LRP pointers were utilized by the students in communicating their investigation in detail. Qualitative assessment of the laboratory reports indicated students made efforts to write detailed paragraphs under each heading that was given as a prompt. They wrote the aim and hypothesis under separate headings which clarified the larger objective of the task and the specific investigation they carried out. For the heading 'theory, each group selected the content from the reading material that they thought described the theory of their investigation. Even though the procedure was mentioned in the reading material, students had to include the exact details of the steps for their investigation as the variables were chosen by the students. Further, students substantiated their data with the necessary pictures. The data interpretation and discussion section required students to offer explanations for the results they obtained. This discussion was also improved in its quality as the students progressed in terms of inquiry level. Thus, the analysis of data from Study 2 indicated that the students progressed in terms of formulation of the hypothesis, data evaluation and discussion of results as the inquiry levels for the laboratory tasks enahnced incrementaly.

8.8 Summary

The chapter describes the study to answer the research question on the impact of incremental inquiry levels on students' science practice skills(hypothesis, data interpretation and the discussion of the results). The results of the analysis of LRP-based lab investigation reports indicated that the quality of hypotheses and the explanations offered for the observations and results enhanced as students progressed with inquiry levels. The short course started with a lab task on the synthesis of the indigo dye that was low on cognitive demand. For this task, students first had to identify the variables which were less in number and then follow the given experimental procedure which was relatively easy. The complexity was enhanced for Lab 2 as the number of variables was more and the experimental procedure too was a bit more complex. In addition, students had to do some mathematical calculations before carrying out the dyeing process. They were expected to prepare solutions based on the chosen variable, adding to the complexity. Further, the next two labs on analysis and treatment entailed designing the experiment and thus were higher on the inquiry level. The procedure for chemical oxygen demand too was lengthy and involved some skills in using apparatus. The detection of the endpoint of titration also required a careful assessment. All these aspects added to the complexity of the task. Students had the freedom to explore what they choose as a variable and thus they had ownership of their investigation and learning.

One of the important aspects that contributed significantly towards students' learning of science practice skills is sustained engagement. Instead of independent inquiry tasks, a series of related tasks is useful for coherent thinking in connecting the learning from each lab. As the inquiry level increased to level 2, students had to take the help of resources such as peer discussion, reading material and the Internet. The efforts must have contributed to their learning. All these factors along with the well-reasoned underlying structure of the courses(gradual enhancement in inquiry levels) impacted the gaining of students' science practice skills. Though more data collection would help in generalizing the outcome of this study, further work was affected by the pandemic and more trials on this short course could not be conducted in diverse classroom settings. Such trials will lead to an enriching understanding of the design of the course. This work is published by the researcher in Varadarajan and Ladage, 2022b

Chapter 9

Summary and conclusion

9.1 Overview of the chapter

This chapter presents the overall summary of the research study described in the thesis. As a background to the planned study, the CER literature on undergraduate chemistry lab education was reviewed. The literature describes the merits and demerits of conventional chemistry lab education with an emphasis on adopting inquiry-based approaches for engaging students in higher-order cognitive skills. The review also indicated that Problem-Based learning is one of the promising approaches which have been widely adopted for undergraduate chemistry laboratory education.

The study then analyzed two sets of laboratory manuals (six manuals across three years of the undergraduate curriculum prescribed by Mumbai University and Savitribai Phule Pune University). The syllabus in these manuals is followed by approximately 1500 affiliated colleges and the colleges from where the data was collected for the study. The manuals were analyzed for content, objectives, experiments with real-world context, green chemistry approach, and levels of inquiry.

The analysis indicated that these lab manuals foster the conventional style of performing experiments, in which the procedure given in the manual is strictly followed. Additionally, a survey questionnaire consisting of six statements on the preferred goals of undergraduate chemistry lab education was given to students (n=58) and teachers (n=37). The results of the analysis suggested problem-solving and sustainable practices as the preferred goals of students and teachers respectively.

Further, to understand the feasibility of introducing a PBL in a conventional lab set-up, the vitamin C PBL module was implemented in Insitute and Authentic settings (two trials with n= 12 and 32). The feasibility study indicated that students found the task interesting as well as challenging. The study suggested the need for integrating scaffolds for a challenging task such as the PBL, especially, when the students are transiting to inquiry labs. The understanding gathered from this study navigated the designing of a short course.

The characteristic features of the short course on indigo dye were - a) integration of different domains of experimental chemistry (organic synthesis, applied chemistry, analytical/environmental chemistry), b) use of the systems thinking approach as a design principle, c) introduction of inquiry in an incremental manner, and d) development of science practice skills, from level 1 to level 2. As this short lab course also involved PBL as a higher-level inquiry task, it was necessary to integrate scaffolding strategies with this task and thus the scaffolds were designed.

After the design of the short course, the research work involved understanding the role of scaffolds (Study 1) and the implementation of the indigo dye short course (Study 2).

The four aspects explored through the research study were, a) the effect of scaffolds on the experimental design, b) the impact of individual scaffolds sequenced as per Kolb's ELC, c) student's perception of working in groups, and d) the effect of incremental levels of inquiry on science practice skills. Study 1 followed a quasi-experimental research design whereas Study 2 followed a case study design.

The following sections summarize the findings of these two studies with their limitations. The implication of the study for researchers, practitioners and curriculum designers are also presented along with possible future directions towards the end of this chapter.

9.2 Study 1

The research work on the role of scaffolds indicated that scaffolds make a qualitative difference in the experimental design for a complex indigo PBL laboratory task on analysis and treatment of wastewater generated through the synthesis/dyeing of yarns by the indigo dye. The scaffolds provided an opportunity for students to experience the first three stages of Kolb's ELC i.e., the Concrete Experience stage (through precursor task and reading material), Reflective Observation stage (through structured group discussion) that led to the Abstract Conceptualization stage (flow chart of the experimental design) which answers the second research question on scaffolds. The students perceived the indigo task as intriguing and challenging.

The experimental design generally includes multiple logically sequenced steps, also taking into consideration the feasibility of execution in the lab. In addition, it involves planning for the chemicals and measurement tools too. This presents the requisite challenge for the given task. Thus, designing an experiment can be thought of as a higher-order inquiry skill. Students need support in such a challenging approach to laboratory work. In addition, the chemistry laboratory in itself is a complex learning environment as claimed by Agustian and Seery, 2017. The results from the study highlight the usefulness of the scaffold in the PBL laboratory learning space.

The first scaffold, the precursor task with simple and familiar content helped students in identifying important aspects related to designing chemistry experiments, such as background information, stepwise plan, calculation, observations, measurements, data representation and analysis. Comparison of the process/procedural flow charts of the precursor and main indigo tasks helped students to identify the missing components such as quantities and concentrations of chemicals in the latter. The precursor task played a crucial role in helping students understand the components of experimental design through a self-directed approach.

The second scaffold provided to the students was the reading material. It was expected that the targeted reading material would help students to focus on the information required to devise the experimental design needed for the laboratory task. Based on the results obtained, it can be inferred that presenting compiled information in the form of reading material may not be sufficient for students to plan executable experimental designs aligned with all the module objectives. The entire content of the reading material was new to the students, which may have added to the cognitive load. Further, there is a need to bridge the gap between learning the content to applying it for formulating the ED. One possible way to enhance the impact of the reading material is to include reflective questions at the end of each section (Varadarajan and Ladage, 2022a). Additionally, the extension of the given time for reading and discussion of the contents can be considered. These aspects may help students to be better engaged cognitively with the reading material.

The third scaffold, the structured group discussion is important as it provides an opportunity for metacognitive engagement. In the current study, this scaffold helped in the reorganization and reconstruction/refinement of students' initial experimental design. This finding is supported by a study by Lu et al., 2014 which highlights that group discussion gives affordance for making students' thinking visible, leading to correction, modification, and knowledge-building through collaboration.

The structured group discussion also helped students to feel confident and recognize that the task was equally challenging to all the groups. Each group had a different perspective and way to solve the given problem. The structured group discussion helped in making such diverse thinking visible and provided opportunities for different groups to deliberate their ideas and views. Though the precursor task and reading material provided the necessary prior information, it was the structured group discussion that helped in making the experimental designs concrete which could be executed in the laboratory. Thus, the scaffold namely, structure group discussion is of great significance, especially, in an open ended, complex and challenging indigo PBL task.

Based on the results and the arguments presented above, it can be inferred from the study that the use of all three scaffolds, i.e., the precursor task, reading material, and the structured group discussion, is important and it leads to a quantifiable and quality difference in the experimental design of a PBL task such as indigo. The scaffolds were useful and helped students plan the experimental design which is an important antecedent to the self-directed PBL laboratory investigation.

Additionally, the data suggests that the scaffolds that were planned served the dual purpose of helping students in formulating the ED of the complex PBL task and practising science skills. For example, the precursor task helped in ED of a simple PBL task, group discussion helped in engaging in argumentation and construction of explanations. Both of these are two important science skills.

As per Kolb's Experiential Learning Cycle (ELC), students undergo four stages for meaningful learning. In the current study, the scaffolds were planned to align with the stages of Kolb's Experiential Learning Cycle, for example, the precursor task, reading material, and group discussion, were aligned with Concrete Experience, Reflective Observation and Abstract Conceptualization stages, respectively. The study suggests that the scaffolds provide a way for students to move through the first three stages in the ELC sequence which led to meaningful learning to design the experiment. The experimental plan is crucial for students to apply in the fourth stage of ELC i.e. the active experimentation stage that corresponds to the lab work. This study was scoped to explore the first three stages corresponding to the pre-lab work involving the designing of the experiment.

Scaffolding also followed some of the pre-lab strategies suggested by Agustian and Seery, 2017; for example, a simple precursor task given before the main PBL task aligns with a simple to complex task strategy; the representation of the procedure in the form of a flow chart is aligned with the whole task strategy suggested by Agustian and Seery, 2017. The scaffolds proved to be effective for the PBL task because of the sequencing of scaffolds as per Kolb's cycle and at the same time, adopting the scaffolding strategies based on the model proposed by Agustian and Seery, 2017.

Further, as a part of the study, students' perceptions about the module were collected through a questionnaire. The analysis of the responses suggested that students found the designing of the PBL experiment a challenging and interesting approach. They thought the tasks engaged them cognitively and the group work kept them motivated to execute the collectively formulated ideas in the lab. They appreciated group discussion as they came to know the reasoning and thinking of other group members while the concepts and newer ideas were getting discussed. While many students found the group discussion helpful/useful, a few students mentioned that the prolonged discussion at times was getting tedious.

The questionnaire data also suggested that small group formation needs greater attention as some students felt that all the members of the small group did not take equal responsibility or were dominating. Similar results were obtained by another study on PBL by Tosun and Taskesenligil, 2013, which quotes students complaining about the group structure and distribution of the task.

9.3 Study 2

Study 2 explored the impact of incremental inquiry levels on science practice skills. The laboratory reports (n=16, 4 reports per lab) by students were analyzed. Students generated the lab reports by following Laboratory Report Pointers (LRP). LRP included some of the conventional pointers (aim, chemicals, theory, procedure) and some inquiry-related pointers such as hypothesis, qualitative and quantitative data, results and discussion.

The qualitative assessment of the lab reports suggested that introducing the incremental levels of inquiry is feasible and appears to be a useful approach for transiting students from conventional (level-0) to PBL-based (level-2) inquiry laboratory.

It was observed that the quality of their hypotheses improved as they progressed towards the lab task involving higher levels of inquiry. The research data suggested that even when the nature of tasks became complex within the same or subsequent level of inquiry, students could identify variables, think of a testable hypothesis, and collect the required data even though there was some variation in the quality between the small groups.

For higher levels of inquiry such as PBL, students had to engage in self-directed learning by accessing multiple resources including reading material, discussion with peers, internet sites, etc. Such efforts enhanced the quality of explanations offered by students for their observations as indicated by the data.

A sustained engagement with multiple inquiry tasks of this short course helped students in practising science skills. This view is supported by a study by Cacciatore, 2014 which suggests that students need to conduct several inquiry experiments to acquire strong experimental skills. Further, Domin, 1999a suggests that students should be allowed to practice and develop their inquiry skills. Thus, Study 2 indicated that the students gain science practice skills as the inquiry level advances engaging them with the inquiry tasks for a longer duration.

9.4 Challenges in implementation of PBL

Chen et al., 2021 present an extensive review of 108 articles to understand the reported challenges in the implementation of PBL. The review found that researchers report the challenges for teachers, students, institutes and culture as four different categories. Some of the challenges mentioned are assessment of PBL, time availability, facilitation training for teachers, continuous training for students' skill development, and design of problems. My study has been carried out in an Indian context. The first challenge, in my opinion, is to develop a PBL module that is contextually relevant to learners in the Indian context. Equally important is to think about the available infrastructural facilities. The PBL module that depends on sophisticated technical facilities may not be suitable for state colleges in India which often have moderate facilities. Presently, chemistry lab courses at the UG level are a collection of several isolated experiments with emphasis only on the final result. Such an outlook needs to be changed with continuous deliberation with teachers, and curricula designers. It is important that the capacity-building programmes for teachers teaching at the UG level are planned. Teachers need to assume the role of facilitator for meaningful implementation of approaches like PBL which is yet another challenge.

9.5 Implications of the study

The following section presents the implication of the study for curriculum designers, practitioners, and researchers who want to venture into understanding teaching-learning issues and improvement in the context of chemistry lab education at the undergraduate level.

9.5.1 For designing inquiry modules

For designing inquiry modules, the study indicates that enhancing inquiry in an incremental manner is a promising approach. The emphasis on Systems Thinking Approach as a design principle is useful for noticing the connections between various subsystems and the experiments within the course. Understanding such interconnections is necessary for adopting a holistic outlook required for problem-solving during chemistry laboratory work. The study suggests a way to connect lab experiments from multiple domains into a short course while retaining the learning objectives of individual labs. The design of such a course also opens the possibility to bring interdisciplinarity/multidisciplinarity to the chemistry laboratory learning process.

The curriculum designers should also consider the incremental approach to introducing inquiry because adequate engagement with the inquiry tasks is needed to internalize the science practice skills. The study suggests that PBL chemistry laboratory curriculum development should consider the use of a combination of scaffolds with special emphasis on structured group discussion. Many times educational needs are contextual. Such design and development should consider the local instructional needs/contextual needs as also for a simple or a complex task. The complexity of the task can be judged based on the number of variables, steps involved in the investigation, new concepts involved, and the minimum required time for completion of the task.

Another aspect is, adopting the LRP format for reporting the inquiry lab investigation. In my opinion, the LRP format goes closer to the journal paper format for scientific communication because while reporting students need to provide evidence and draw data-based conclusions.

The module developed as part of this study, adheres to the most recent laboratory course guidelines provided by University Grants Commission (UGC, a regulatory body involved in curricular framework for higher education in India) in its "Curriculum and Credit Framework for Undergraduate Programmes". According to these guidelines, there is an emphasis on the shift from teacher-centric to student-centric pedagogies and from passive to active/participatory pedagogies. The experimental module with the PBL approach(PBL indigo module) is in compliance with the UGC guidelines, as, PBL is both student-centric and is one of the most adopted active learning pedagogies. Further, the guideline also suggests that the laboratory should provide an opportunity for students to apply principles and theories. The chemical concepts of the indigo PBL module fit well with this criterion as students apply a wide range of organic, inorganic and physical chemistry concepts in the laboratory scenario. Further, UGC guideline encourages the use of self-study material and teamwork and these are very much integral to the indigo PBL module. As far as the assessment is concerned, the guidelines advocate team project reports, observation of practical skills and problem-based assignments. All these aspects are also a part of the indigo module. Thus, the design of the module as an example showcases how all these facets which are a part of the newer curriculum framework (National Education Policy 2020), can be integrated into designing short chemistry courses for chemistry lab education.

9.5.2 For practitioners

The work presents a pedagogical approach for the gradual transition from a conventional laboratory to an inquiry laboratory and finally to a PBL environment with the help of multiple scaffolds. The three inquiry-based instructional resources namely, vitamin C (Appendix C), vinegar (Appendix E), and indigo (Appendix-G) developed in the current research study are available to practitioners. All these modules are field tested in the authentic setting of two state colleges in India. The efforts towards converting the existing laboratory experiments (vitamin C and vinegar) into inquiry modules indicate clearly that the resource constraint cannot be cited as a reason for not shifting to inquiry labs as was suggested by one of the authors of the manual in the interview. The approach used in this study will encourage practitioners to undertake such developmental work and implement the same in their colleges. Additionally, based on the data of this study, practitioners can be encouraged to provide LRP pointers to students to write the laboratory report. This format provides an opportunity for students to reflect on the entire process of investigation thereby bringing the required connection between the hypothesis, results, and explanations.

The rubric created for the assessment of science practice skills is a deviation from the present ways of assessing the labwork which is essentially based on the correct end result and a well-maintained lab journal. Researchers such as Hodson, 2005 recommend laboratory or investigatory skills should be the focus of assessment. Detailed rubrics with scores for all the steps that evaluate the expected learning outcome provide an objective way of assessing students' performance in the lab. The practitioners could devise such rubrics rather than evaluating the lab journals which in no way indicate students' lab skills or science practice skills. Additionally, peer assessment of how the group members participated in tasks could also be a way for a collaborative learning experience such as PBL. Further, the research also provides insights for the practitioners for converting their teaching into action research.

9.5.3 For researchers

The study indicates that Kolb's theory fits in the context of chemistry laboratory education since all the stages could be mapped across the pre-lab, lab and post-lab components of laboratory learning. By using this theory as a framework, students' engagement with the first three stages was investigated. The study attempted to understand how a combination of scaffolds sequenced according to the stages of Kolb's Experiential Learning Cycle (ELC) facilitated students to accomplish the given task in a complex learning environment such as the PBL laboratory. Further, students' responses to the targeted scaffolds helped to understand the engagement level of students at each stage of Kolb's cycle. Thus, by using multiple data sources, that is, ED scores, students' perception questionnaires, and group discussion, evidence could be gathered for the effectiveness of the scaffolds for student groups that differed in their prior academic scores. The work further validates the use of Kolb's learning cycle as a theoretical framework for chemistry laboratory learning space. Future work can explore the active experimentation stage in the context of a chemistry laboratory i.e. the fourth stage of ELC.

9.6 Limitations of the study

The short course was implemented with only one cohort as a case study to understand the feasibility of implementation of incremental inquiry experiments in the authentic setting. It is important to carry out more trials which will be useful for the generalization of the impact of the short course and the use of LRP prompts. One more study was planned which could not be carried out due to the onset of Covid-19 pandemic. For the study on scaffolds, the sample size varied from 4 to 6 teams of students for each of the four workshops. The work has not explored how the sample size affects the group discussion. Further, the absence of an un-scaffolded group in the authentic setting did not allow us to draw a comparison between the un-scaffolded and scaffolded group in the authentic setting. Though the study on scaffolds has been carried out in two settings with a difference in the prior academic achievement levels of students, the transferability of the study to a different setting will have to consider the background of students before implementing the PBL module.

The impromptu feedback sessions during the post-lab work of lab-1 and lab-2 were not a part of the research design. The feedback session was not recorded which would have given us an insight into the impact of these sessions.

The other limitation was posed by the then-prevailing Covid-19 pandemic in collecting more data related to the short course that was completed in March 2020. Online interview with students was conducted to collect more supporting data. The audio quality of the online interviews was not good due to connectivity/recording issues. The supporting data through interviews would have added substantial value in gathering feedback.

9.7 Future directions of the study

One of the interesting future works would be to understand whether students can relate various subsystems that are integral to the indigo short course. In other words, the exploration of understanding the systems thinking approach (not explored in the present study) will be important. Another important extension of the study could be to explore how the fourth stage of Kolb's ELC i.e. the lab experiment leads to concrete experience thereby completing the cycle.

The evaluation of the experimental design in this study indicated the scope for improvement in its quality. The need for an additional scaffold and the effect of the precursor task on the main PBL task can be explored in greater detail.

During the pandemic, the LRP prompts were used as a part of online chemistry lab courses. Though the environment was very different, the LRP prompts did help in generating meaningful responses related to science practice skills. Thus, investigation can be done for the standardization of these prompts to enable their comparison with other standard formats.

I am inclined to see this work being implemented as a part of the UG syllabus. A study is being planned in the immediate future to collect data during the capacity-building workshop of undergraduate chemistry teachers. This workshop is funded by the State Government for the implementation of inquiry in higher education institutes. The thrust of this workshop would be to help the teacher experience the indigo module so that it can be taken to their college laboratory space. The research would entail understanding the challenges faced by the teachers in adopting inquiry and PBL approaches. Further planning involves engaging the teachers in designing an action research program to understand the implementation challenges in diverse classrooms.

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Appendix A: Consent Form

Homi Bhabha Centre for Science Education(TIFR)
V.N. Purav Marg, Mankhurd,
Mumbai - 400088

Consent Form (Teachers)

We are giving you a questionnaire designed to understand your view point about the chemistry laboratory program. Your honest opinions/impressions/responses will be useful to us. The responses given by you in the questionnaire will be used for chemistry education research purpose only and identity of the teacher will be kept confidential. We thank you for your cooperation.

(To be filled by teacher)

I give my consent to use the answers given by me for the chemistry education research purpose only.
Signature of the teacher: Gender:
Date: Qualification:
Name of the college/school currently associated with:
Number of years of teaching chemistry:
Number of years of teaching chemistry laboratory experiments:

Consent Form (Students)

I, Sujatha Varadarajan, a researcher at HBCSE, am involved in developing modules for imparting science practice/ inquiry skills using alternative pedagogy for Chemistry Laboratory Education. We are trying these modules at various colleges to get feedback from students.
As a part of our study, I may require your responses in the questionnaire, task-sheets (lab reports) and interview (if required).
The responses given by you in the report, discussions/questionnaires/task-sheet /interview will be used for chemistry education research purpose only. Your honest opinions / impressions / responses will be useful to us.
Your participation in the study is completely voluntary and there is no monetary compensation. We assure you of no-risk and will keep your personal identity confidential.
I thank you for your cooperation.
Sujatha Varadarajan

(To be filled by students)

I have read the above information carefully and am aware that my responses will be used for chemistry education research purpose. I hereby give my consent for using the responses in the questionnaires and task-sheets, Audio recordings, for the purpose of chemistry education research.

Signature of the student:
Name (optional): Gender:

12^{th} grade marks:
12^{th} grade board (CBSE/State):

Number of years of exposure to laboratory education
In the school/junior college:
In the undergraduate course:

Appendix B: Perception questionnaire on laboratory goals

Rank-order questionnaire

You are being given this questionnaire which has six statements related to what could be the goal of chemistry laboratory education. You are requested to rank them from 1-6. The most preferred statement gets rank-1 while the statement with lesser priorities is ranked subsequently. Rank-6 would mean last on the priority list. You could use a pencil initially and the final entries could be made with a pen.

1. The Chemistry laboratory should emphasize co-operative attitudes (helping each other), collaborative learning (sharing ideas and discussing).

   ☐

2. The chemistry laboratory should enhance awareness about environmental problems and viable solutions. This includes promoting economic use of resources such as energy, chemicals and advancing green chemistry (environmentally friendly) practices.

   ☐

3. The laboratory should show chemistry as a challenging subject worth pursuing so that students choose chemistry as a career.

☐

4. The purpose of chemistry laboratory should be to get familiar with important chemical facts, strengthen understanding of concepts in chemistry learnt in classroom and verify them experimentally.

☐

5. Given a problem situation, students should be able to design experiments, analyze and interpret data to solve a problem. They should learn to handle any difficulties faced during the experimental investigation. In other words, Chemistry laboratory curriculum and instructions should be geared for developing problem-solving ability in experimental chemistry.

☐

6. The purpose of chemistry laboratory should be to develop skills like handling of glassware, chemicals, and instruments; learn and master different standard operations e.g. as what is needed in wet laboratory. This includes, importantly, awareness of safety issues in chemical experimentation.

☐

Appendix C: Pilot Study, vitamin-C

Lab Task: Estimation of vitamin C

Lab task sheet

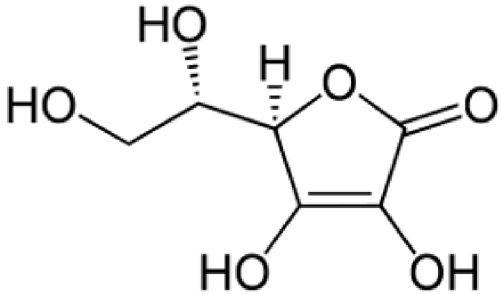
Developed by -Sujatha Varadarajan and Savita Ladage

Introduction: Analysis of Vitamin C

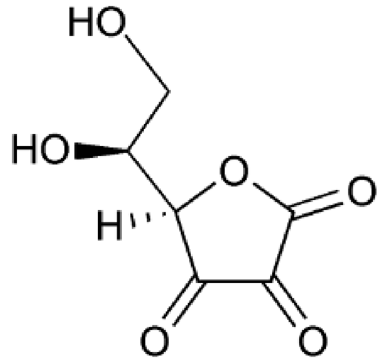
Vitamin C is found to be very effective in enhancing immunity and preventing cold. It also helps in absorption of iron in our body. Of the known species, primates including human beings cannot synthesise this vitamin. Fortunately, most of the vegetables and fruits we eat contain vitamin C in varying amounts. The daily recommended quantity for human adult is approx. 60 to 100 mg. In cases of deficiency among human beings which leads to scurvy, Vitamin c supplements are prescribed in the tablet form too.

Vitamin C is the common name for Ascorbic acid ($C_6H_8O_6$-structure I, Molecular mass=176.5g). The oxidised form of ascorbic acid is called as dehydroascorbic acid ($C_6H_6O_6$-structure II).

(a) Structure I



(b) Structure II



It is possible to determine vitamin C content in each sample in the undergraduate laboratory by titration techniques. However, both the natural form and tablet form of vitamin C often has presence of some other substances which may/may not hinder with estimation of vitamin C.

In the current experiment, you will be estimating amount of vitamin C in the sample provided to you. In fact, your estimation will help in understanding whether the given sample/s has the expected amount of Vitamin C as per the label.

Part 1

The table below gives information about some of the substances available in the market which contain vitamin C and may contain some other ingredients. You may choose any one of these as sample for your analysis. Please read the label carefully.

Table C.1: Label for vitamin C samples

Tablet Limcee- (mass- 500mg/tablet)	Tablet Celine - (mass- 500mg/tablet)	Glucon D packet (mass -200 gm)	Tang juice Powder sachet (mass -125 gm)
Values (mg / 500 mg)	Values (mg / 500 mg)	Values(mg /100 g)	Values in mg per 100g
Ascorbic acid - 100 & Sodium Ascorbate 450mg (this is equivalent to 400 mg of ascorbic acid)	Ascorbic acid=500	Vitamin C =50 Carbohydrates=92 Calcium =114 Other ingredients	Vitamin C= 107 Sugar= 948 Other ingredients=175

The main aims of the current experimental analyses are,

1. To determine amount of vitamin C in the given sample.
2. To compare whether the amount determined is same as the amount of vitamin C mentioned on the label or wrapper of the sample.
3. To reflect whether there is any kind of chemical interference caused by the presence of other ingredients during the estimation.

Sample chosen ....

1. Explain in brief, reason for your choice of sample.

Part 2

Methods available for analysis of vitamin C

The following are some of the methods of analysis of vitamin C. You have to analyse the sample using both of the given methods and compare your results.

Method 1: Iodometric titration of vitamin C

In this method, ascorbic acid is oxidised by iodine to dehydroascorbic acid. Sample containing ascorbic acid, potassium iodide solution (in excess) and hydrochloric acid (with pH=1) are taken in a conical flask. The solution is then titrated with standard potassium iodate solution using starch indicator (at least 0.5 ml of indicator must be added during titration).

When potassium iodate reacts with potassium iodide in presence of hydrochloric acid, Iodine is liberated in the flask. The liberated iodine immediately reacts with ascorbic acid till all of ascorbic acid present in the solution is oxidised. When the entire amount of ascorbic acid is consumed, then the iodine reacts with starch to give blue black colour. The appearance of blue black colour is the end point of titration.

Write balanced equations for the reactions.

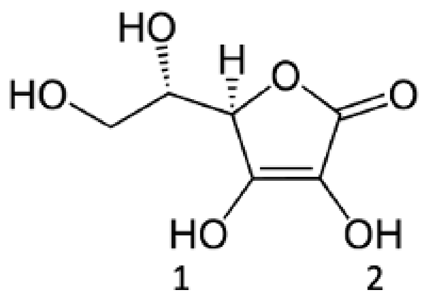
Reaction of potassium iodate with potassium iodide Reaction of iodine with ascorbic acid

Method 2: Titration using sodium hydroxide solution

Since ascorbic acid is a weak acid, it can be titrated directly with sodium hydroxide using phenolphthalein as an indicator. Sodium hydroxide is taken in the burette and the sample containing ascorbic acid is taken in the conical flask. Appearance of light pink colour is the end point of the titration.

Carefully examine the structure of ascorbic acid to answer the following question.

The hydrogen/s of hydroxide groups that may be replaced by sodium atoms are indicated by numbers 1 and 2 in the below structure.

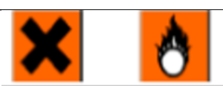


1. State whether only one or both hydrogen would be replaced? Explain your answer.

2. If you think, only one of the two hydrogen atoms is replaced during reaction with sodium hydroxide, then which one of the two, 1 or 2, would be replaced? Explain your answer.

3. Write balanced equation for the reaction between ascorbic acid and sodium hydroxide based on above reasoning.

Chemicals and glassware provided

KIO_3		Harmful , oxidising agent
KI		Skin irritant , aspiration hazard
HCl		Skin irritant, corrosive to metals, hazardous to aquatic environment
Sodium hydroxide		Corrosive

Record Sheet

Method I: Iodometric titration

Method II: Acid –Base titration

For the method I and II, the burette reading of the titration is expected to be between 10-15mL. Calculate the amount (in g or mg) of the sample you will weigh for the analysis if the final volume of sample solution may be taken as 100 mL.

Calculations for Method 1

Calculations for Method 2

You need to show your calculations to the experts before you proceed for the actual experiment.

Describe in brief how you will prepare the sample for analysis (Note that the final volume of the sample solution will have to be 100 mL).

This space may be used for rough work.

Part 3

Method 1

Instructions: You may take maximum three titration readings for the sample solution prepared by you. However, if you want to take more readings/trials with different sample weight/volume, you can approach the instructor for the same.

Mass of the sample weighed:

Volume pipetted for titration:

No.	Burette readings (mL)	I	II	III
1	Initial Reading			
2	Final Reading			
3	Difference			

Calculations for mmol of ascorbic acid present in sample taken for analysis

Calculations for amount of ascorbic acid (in g) present in sample taken for analysis

Rough Page

Method 1

Mass of the sample weighed:

Volume pipetted for titration:

No.	Burette readings (mL)	I	II	III
1	Initial Reading			
2	Final Reading			
3	Difference			

Calculations for mmol of ascorbic acid present in sample taken for analysis   Calculations for amount of ascorbic acid (in g) present in sample taken for analysis

Present your conclusions based on results obtained by you for both the methods.

You may use backside of this sheet for writing further.

After your finish the calculations, note the amount of vitamin C obtained by you from method I and method II in your notebook as you may need it for part 4 that will be given to you after submission of Part 3 sheet.

Part 4

1. Compare the amount of vitamin C as obtained by the two methods with information given in the table-1 (refer to Part1) and write your conclusions.

2. Is there any difference between the values of vitamin C obtained by you and that given in the table for the sample chosen by you? If yes, can you state one or two possible reasons?

3. Suggest one or two ways that will help to reduce the difference between the values of vitamin C obtained by you and that given in the table for the sample chosen by you.

4. Write the various chemical concepts that you have learnt by doing these experiments.

Group discussion

Group discussion would require group members to interact with other groups who have analysed similar sample.

Groups will be formed also to discuss amongst the members who have analysed different samples.

All these discussions will have to be presented.

Pointers for group discussion and presentation:

1. Collect and collate-
   a) the inferences from all the group.
   b) all the concepts and skills learnt
   c) difficulties/challenges in the experiments performed by all of you.
2. Compare the methods with respect to
   a) Ease of performance
   b) Calculations involved
   c) Chemical interferences of other components present in the sample

Rough Page

Expected burette reading of KIO_3 =
No. of moles of 0.002 M potassium iodate =
Molar equivalence=
No. of moles of AA in the pipetted volume for end point =
Total moles in the made up volume =
Mass of ascorbic acid containing the required moles=

Expected burette reading of NaOH =
No. of moles of 0.01 M sodium hydroxide =
Molar equivalence=
No. of moles of AA in the pipetted volume for end point =
Total moles in the made up volume =
Mass of ascorbic acid containing the required moles=

Appendix D: Feedback Form: Pilot study on vitamin C

Your response in the feedback form may be used for Chemistry Education Research purpose. Your honest opinion is valuable to us as we will use it for improving the experimental module further. Thank you for your cooperation!

1. Did you find the lab experiment interesting?
2. Comment on the following as to how you found the lab task sheet.
   - Introduction:
   - Language:
   - Length:
   - Information provided:
   - Any addition/deletion needed:
3. As part of this experiment, you worked in group and interacted with other groups. Was this a distinct experience from your regular lab? Explain whether such interactions are useful/not useful and If so, why?
4. Comment on:

a) The Strengths of such lab work

b) The Weaknesses of such lab work

5. Assuming you are designing experiment related to Vitamin C with the same chemicals - state two aims that would like to explore other than what was given to you.

6. What was the interesting part of the experiment?

7. What was the boring part of the experiment?

8. What difficulties did you face while performing the experiments?

Appendix E: Precursor task for indigo lab

Suitability of Commercial vinegar as a preservative for pickles

Introduction

The word "Vinegar" is derived from the French words - vin (wine) and aigre (sour). The use of vinegar to flavour food is centuries old and it has also been used as a medicine. Many of us use vineger in our food preparation to flavor and preserve foods. It is also used as an ingredient in salad dressings and marinades for centuries. Vinegar, *a liquid fit for human consumption*, is produced from a suitable raw material of agricultural origin, containing starch, sugars, or starch and sugars by the process of double fermentation. It contains a specified amount of acetic acid. Generally, name of the raw material used for producing vinegar is indicated in the label of vinegar bottles, for example, malt, cider (apple) or wine vinegars. In brief vinegar can be considered as dilution of acetic acid that is produced from any natural carbohydrate source.

Vinegar sold in market can have different concentrations of acetic acid which is indicated in the label of the vinegar bottles. The most widely used concentration range is 4% to 15% (v/v). However, sometimes, the concentration of acetic acid can be 25% or even above (Such sample is called as a vinegar essence).

One of the important usage of vinegar in market is in pickles as preservative. The concentration of acetic acid in such vinegar must be in range of 5%-6%.

Thus, it is important to determine the acetic acid content of the vinegar to use it as preservative for pickles.

Amount of acetic acid in vinegar can be determined by titrimetric method using a strong base and a suitable indicator. We can carry such experiment in undergraduate chemistry laboratory.

Sodium hydroxide (NaOH) solution can be used as the titrant (filled in burette) with Phenolphthalein as an indicator. On reaching the end point, a light pink colour will persist in the flask.

(References: http://www.madehow.com/Volume-7/Vinegar.html)

The following vinegar bottles from the market are available for use. a) Apple cider vinegar b) Rice vinegar c) Distilled white vinegar

Your task is to plan an experiment to identify the vinegar sample which can be used as preservative for pickling.

The information given in above may be used for planning this experiment.

You are expected to work in groups to chart out what steps you would follow to carry out the investigation.

In addition, once your plan is finalised you are expected to draw a flow chart of the plan.

You may assume that all the required chemicals, glassware, instruments are provided to you.

Rough Work

Write-up of the plan

Flow chart

Consider your flow chart of the experimental plan. In the following table, indicate different steps from your flow chart in the left-hand column and explain its purpose in the column on the right.

Appendix F: Indigo Literature

Reading Material Codes In the given literature/reading material, you are requested to highlight sections according to the pointers given below.

A) Important information needed for planning the laboratory work

B) Already known information

C) Information that discusses theory/concept related to the task

D) Useful background information related to the task

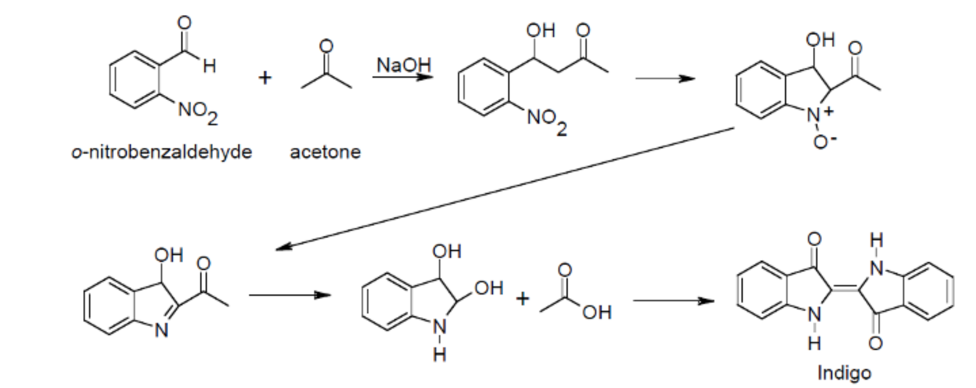
E) Information that needs further reading

Introduction

Indigo is a blue dye that has been used to dye cloth for thousands of years. Its first use was by ancient Egyptians to dye mummy cloths. The blue dye indigo has been used in India for about the last 4000 years. It was derived from the plant Indigofera tinctoria. Phoenician traders and migrating peoples gradually introduced this dye to the Mediterranean area and then spread to Europe. In Northern Europe from the Bronze Age (2500 – 850 BC) people used a blue dye, waod from the plant Isatistinctoria. It has since been discovered that this plant contains the chemical indigo, but due to other compounds in the plant it is not a 'pure' blue like the Indigofera.

It was first artificially synthesized in 1880 by J. F. W. Adolph von Baeyer who won the Nobel Prize in 1905 for his work with organic dyes. Although Baeyer's synthesis method does not work well for producing large amounts of indigo that would be needed for industrial applications, it works well for micro scale production.

Indigo production through the Baeyer-Drewson reaction involves reacting o-nitrobenzaldehyde with acetone under highly basic conditions. The series of reactions below outlines the steps that the reactants go through in forming the final product.



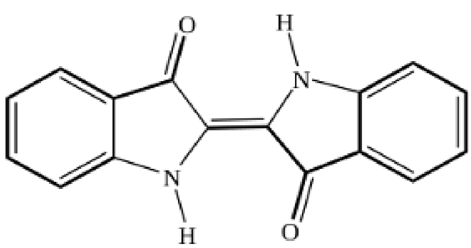
Labtask-1, Synthesis of Indigo

- Procedure for the synthesis of Indigo:
- To a 100 ml beaker add: a 1-cm stir bar, 5mL acetone, 5mL distilled H 2 O, and 0.50g o-nitrobenzaldehyde. Begin stirring. Add 2.5mL 1M NaOH drop wise over a period of 5 minutes.
- Next, let the mixture stir for 5 minutes to allow it to return to room temperature.
- Using a funnel, vacuum filter the contents of the vial.
- Next, rinse the beaker with 10mL H_2O and add this to the filter before the product becomes dry. Before this liquid passes though the filter completely, wash the filtrate with 5mL cold 95% ethanol.
- Remove the product from the filter, allow it to air dry, and then weigh the dry product.
- Indigo's melting point is above the range of laboratory thermometers so do not attempt to find the melting point of the product.

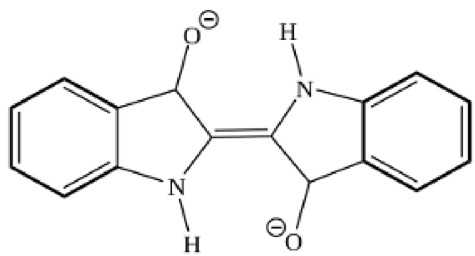
Draw a flow chart of the above procedure.

Colour and Indigo

A coloured compound absorbs visible light (gains energy) as its electrons are excited. The colour of the compound is the complementary colour of the light which is absorbed. From the electronic spectra, it can be seen that the indigo compound has its absorbance maxima at 675 nm, which is higher than the leucoindigo which has its absorbance maxima at 396 nm. This is expected because the indigo [structure (a)] has a greater number of conjugated double bonds(− double bonds are separated by a single bond) than the leucoindigo [structure (b)]. The electronic spectrum of indigo shows where it absorbs light. As it absorbs wavelengths around 675 nm (in the red region), we see it as blue. The electron spectra of leucoindigo shows that it absorbs light in the violet and blue regions and we see it as yellow.



(a)

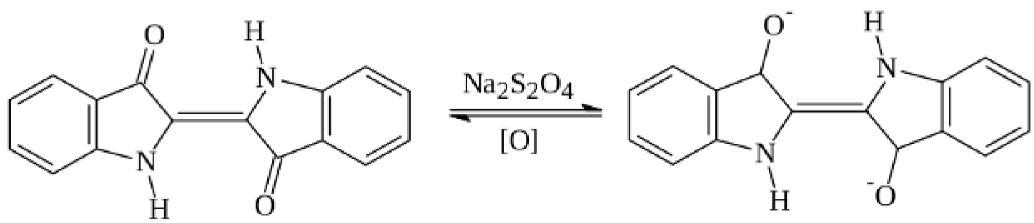


(b)

Vat Dyeing

Indigo, like most commercial dyes, is water insoluble. This means that the dye will not wash out, however, it also means that indigo cannot be introduced into fabrics by simply immersing them in an aqueous solution of the dye. In order to introduce indigo into fabric a process called vat dyeing must be utilized. Vat dyeing involves reducing the dye to a leuco derivative (using sodium hydrosulfite) which is soluble in a dilute alkali solution. The fabric is immersed in this solution which allows the leuco compound to adhere to the fabric by hydrogen bonding. The fabric is then exposed to air which oxidizes the leuco compound into the dye.

The changes can be represented in the following structures.



indigo

leucoindigo (indigo white)

Procedure of vat dyeing on cotton

1. The indigo sample is taken in a 100 mL beaker with a few drops of ethanol and the mixture is stirred well using a glass rod.

2. 1 mL of deionised water is added to the paste with continuous stirring, after which 3 mL of 2 M sodium hydroxide solution is added.

3. 20 mL of deionized water is taken in another 100 mL beaker and a small amount (a spatula full) of sodium hydro sulfite (sodium dithionite) is added and stirred.

4. Add the solution made in Step 3) to the beaker that contains the indigo dye and cover the beaker with a watch glass.

5. Heat the mixture up to 50 °C on a steam bath (check the temperature occasionally with a thermometer) ensuring that the beaker is covered most of the time. As soon as a clear yellow solution is obtained, add 40 mL of deionised water.(the ‘vat’ is ready)

6. Immerse three small pieces of cotton in the ‘vat’ and leave for 1 hour at 50 °C, occasionally moving the fabric to ensure even dyeing and maintaining the temperature.

7. Remove the cotton with metal tongs and squeeze dry; hang it in the air for about 30 min. to develop the colour and allow the fabric to air dry.

8. After they are dry, rinse with cold water until the washings are clear.

Dyes after application are physically retained by fibre through hydrogen bond and van der Waals forces. Fastness of dyeings depend on size of dye molecule and its solubility in water – the larger the size and lesser the solubility, the better the fastness.

Dye and fibre, both possess required reactive groups to develop dye–fibre attachment through chemical bonding. Nature of bond is mostly ionic (electrovalent), though in some cases, covalent bonds are also formed.

Fastness of dyeing depends upon number of reactive sites attached to the fibre – the greater the number of sites attached, the better the wash fastness.

Wastewater

A large amount of waste water is generated in the process of vat dyeing. One of the main sources of water pollution is dyes and pigments of different classes. Drained out dye baths consist of unused colour having compact structure and hazardous chemicals and are not so easily degradable. Though chlorine, peroxide, ozone treatment and various other methods are effective in removing colour from waste water, the sequence of operation is complicated, uneconomical and time consuming. Typical problems also arise due to use of $Na_2S_2O_4$ and NaOH in vat dyeing. In the following table, are listed different parameters that are associated with the dye industry with the maximum and tolerance limits identified.

Typical wastewater discharge limits

Waste-water characteristics	Max. limit	Tolerance limit of		
		Pollution board	BIS-3306 1955	AMC-1975
pH	6–8	5.5–9.0	5.5–9.0	5.5–9.0
Temperature	45	40	45	45
Total suspended solids (mg/l)	300	100	600	600
Colour	–	–	100	–
Total dissolved solids (mg/l)	–	2600	2100	3500
Oil and grease (mg/l)	**	10	100	100
Compounds of Cr, Cu, Ni, Cd, Zn, Pb, Tin (mg/l)	20 (total)	–	–	–
Phenolic compounds (mg/l)	–	1	5	5
Fe (mg/l)	150	–	–	–
Sulphates (mg/l)	300	1000	1000	1000
Chlorides (mg/l)	–	600	600	600
BOD_5 (mg O_2/l)	600	31	500	500
COD (mg O_2/l)	–	30	500	500
Synthetic detergent (mg/l)	10	–	–	–

*colourless on visualization, **not visibly detectable

Basics of assessing waste-water

Various government and municipal agencies specify norms and methods of measuring waste-water load. In textile process houses, the effluent (waste water) is primarily tested for 'biological oxygen demand' (BOD), 'chemical oxygen demand' (COD), dissolved and suspended solids, pH and harmful factor (COD: BOD5). A calculation of weight of dyeing in respect to total COD of the exhausted and drained bath enables dyer to restrict extent of load for each kg of dyeing (gCOD/kg dyeing). In some cases, dissolved organic carbon (DOC) and total organic carbon (TOC) are also assessed. Needless to say, it is the BOD, which is of paramount importance to ascertain susceptibility of drained out liquor towards its degradation.

Terminology associated with waste-water

Biological Oxygen Demand (BOD)

It is a measure of volume of oxygen required under natural circumstances to degrade pollutants for each litre of liquor. In general, BOD is measured after treating the liquor at 20°C for 5 days and is denoted by BOD5. It is a measure of rate of degradation of pollutant throughout a period of 5 days. However, if degradability of a chemical is very high, instead of measuring BOD5, degradation for 1 or 2 days, e.g. BOD1, BOD2, etc., can be assessed. Similarly, if rate of degradation is too slow, a BOD value can be measured after a period of 10, 20 days, etc. However, assessment of consumed oxygen for 5 days, BOD5, has been accepted as a standard, in general.

Chemical Oxygen Demand (COD)

It provides a measure of oxygen equivalent of that portion of the organic matter in a sample that is susceptible to oxidation by a strong chemical oxidant irrespective of its rate of degradation which under natural circumstances may take several weeks or even years. It is an important, rapidly measured parameter for stream and industrial waste studies and control of waste treatment plants. COD can be defined as milligrams of oxygen which one litre of effluent will absorb from a hot, acidic solution of potassium dichromate.

Dissolved organic carbon (DOC)

Dissolved organic carbon (DOC) is the amount of organic carbon present in dissolved phase after centrifuging or membrane filtration.

Total organic carbon (TOC)

Total organic carbon (TOC) is the organic contaminants, both suspended and dissolved and are expressed in terms of carbon content of the effluent. Higher the carbon content more will be oxygen required to oxidize that to CO_2 and time for complete conversion will be lengthy and vice versa.

Assessment of the waste-water

Assessment of chemical oxygen demand, in relation to BOD, gives first-hand information on how much time the liquor may take for complete degradation. If the BOD5 value of a liquor is 15 mg O_2/l and COD is, say, 75 mg O2/l, the liquor will take 75÷(15÷5) or 25 days for complete degradation. This is true for individual chemicals, but while in mixture, fails to trace out total time required for complete degradation. Forceful oxidation of a chemical in laboratory is possible which under natural circumstances, may be too hard to degrade. In general, BOD helps to indicate rate of natural degradation, while COD predicts how much of oxygen is required and in combination with BOD how many days the liquor may take for complete degradation. BOD5 of a given effluent is always lesser than its corresponding COD. To assess BOD5, the liquor is diluted and a known volume is added to water saturated with oxygen containing trace elements and inoculums of organism. Closed bottles are incubated precisely at 20°C for five days in incubators and the residual dissolved oxygen is compared with that on duplicates measured before incubation; the difference shows consumption of oxygen due solely to the biodegradable organic matter present. Trials are to be made at different dilutions to the test solution, both to observe the effect of dilution and to arrive at a level whereby about half the dissolved oxygen is consumed in the test. The method has several limitations, viz. (i) it is a time-consuming method, (ii) it does not provide information of extent of organic pollutant present in water, that is not degraded by bacteria and (iii) selection of correct bacteria is a must to get consistent results. To assess COD, an oxidant, like $K_2Cr_2O_7$ is mixed in diluted liquor under test in acidic conditions and boiled for two hours to oxidize a part of the liquor; unused dichromate is assessed to know how much has been consumed. The value indicates total organic matter, both degradable and non-biodegradable. Measurement of COD is more reproducible, but limited as some organic contaminants are resistant to dichromate oxidation. Harmful factor is the ratio of COD and BOD5. The lower the ratio, the higher is the rate of degradation of waste-water. A higher value indicates that degradation is too slow and may take longer time. For fairly biodegradable waste water, the ratio should be closer to 1, practically very difficult to achieve.

Solids present in drained out liquor is either in suspended or dissolved state or combination of these two. Dissolved solids must be separated out from liquor; otherwise diffusion of atmospheric oxygen in the sewage will be slowed down.

Suspended solids, on the other hand, clog respiratory tracts or gills of aquatics to kill them. Separation of these is essential to preserve freshness of water body.DOC and TOC both have achieved more importance in recent years, since these represent all organic material present in one or both phases, irrespective of relative ease of oxidation. It should be noted, however, that the above criteria are concerned essentially with organic pollution of effluents. These indicate nothing about the colour, temperature, pH, content of electrolytes or heavy metals present; any of these factors may prove critical in defining the acceptability of an effluent sample. Bio-elimination includes the material removed by adsorption on the biomass as well as that which undergoes biochemical decomposition.

Methods for the analysis of wastewater load

Following are some parameters and the method/s adopted for analysis:

1. **Colour**

   The colour of the drained out and treated liquor is visually assessed against sunlight. The problems related to untreated colour have been described in detail at the end of the section.

2. **pH**

   pH is tested with the help of a pH paper or with pH meter for better precision.

3. **Suspended and dissolved solids**

   25 ml of the sample is filtered through a previously weighed 'Whatman 42' filter paper. The residue on paper is dried at 103±2°C in hot air oven till constant weight is obtained.

   Suspended solid (mg/l) = weight of residue (mg) × 103 / 25

   The filtrate is collected in a porcelain desiccator is dried at 103 ± 2 °C, weighed till constant weight is obtained and extent of dissolved solid is calculated using the same way as that is used for calculation of suspended solids.

4. **TOC**

   TOC is assessed using potassium persulphate which releases – HO free radical on UV-radiation for oxidation of carbon impurities in effluent to CO_2. The TOC analyzer essentially consists of a septum (open end) to inject the sample and reagents at the interior of the analyser, a container which retains waste water under test as well as other additives, two gas connections to sparge unoxidized and oxidized samples, a pump, an oxidizing chamber inside which an UV-lamp is fitted and finally an integrating CO_2 detector to measure extent of CO_2 formed which is directly proportional to TOC in effluent.

5. **Chemical Oxygen Demand**

A boiling mixture of chromic and sulphuric acid destroys most types of organic matters in effluent. A sample of waste water is refluxed with known concentrations of $K_2Cr_2O_7$ and H_2SO_4. The excess $K_2Cr_2O_7$ is titrated with ferrous ammonium sulphate; amount of oxidizable organic matter is measured as oxygen equivalent and is proportional to the $K_2Cr_2O_7$ consumed.

$K_2Cr_2O_7 + 4\,H_2SO_4 = K_2SO_4 + Cr_2(SO_4)_3 + 4\,H_2O + 3\,[O]\uparrow$

I **Procedure**

Materials required:

conical flask of 500 mL capacity with suitable condenser, 0.25N $K_2Cr_2O_7$, ferroin indicator, 0.1N ferrous ammonium sulphate FAS $[Fe(NH_4)_2(SO_4)_2 \cdot 6\,H_2O]$, conc. H_2SO_4, distilled water and $AgSO_4$ crystals.

For standardization of $Fe\,(NH_4)_2(SO_4)_2 \cdot 6\,H_2O$:

To 10 ml of standard $K_2Cr_2O_7$ solution taken in a 500 mL conical flask is added about 100 mL. 30 mL conc. H_2SO_4 is added to it and allowed to cool. The solution is titrated with 0.1N $Fe(NH_4)_2(SO_4)_2 \cdot 6\,H_2O$ using a few drops of ferroin indicator with constant stirring to blue–red end point. Normality of $Fe(NH_4)_2(SO_4)_2 \cdot 6\,H_2O$ = (ml $K_2Cr_2O_7 \times 0.25$) / ml $Fe(NH_4)_2(SO_4)_2 \cdot 6\,H_2O$

For waste water

i) 25 ml of waste water is taken in a 500 mL round bottomed flask, 100 mL of cold water is added followed by addition of 25 mL of 0.25N $K_2Cr_2O_7$solution, 75 ml of conc. H_2SO_4 and 1g $AgSO_4$. The mixture is refluxed for at least 2 hours. The refluxed mixture is diluted to about 350 mL with water and the excess $K_2Cr_2O_7$ is titrated against standard FAS solution using ferroin indicator. The end point is blue–red.

ii) The procedure is carried out for 'blank', with 100 mL water (no effluent) along with 75 mL conc. H_2SO_4, 25 mL of 0.25N $K_2Cr_2O_7$ and the mixture is refluxed for 2 hours . Volume of FAS solution (for blank) is determined. COD (mg O_2/l) = (A-B) × C × 8 × 1000 / mL of sample used Where, A is mL of FAS used for blank, B is mL of FAS used for sample and C stands for normality of FAS.

The procedure of using 25 mL sample holds good for COD values up to 1000 mg O_2/l. For higher COD, all the $K_2Cr_2O_7$ is consumed and the solution turns green. In such cases, it is suggested to dilute the effluent under test with water and the obtained COD may be multiplied by the dilution factor to get actual COD of effluent.

II **Alternate procedure**

Reagents

Standard potassium dichromate solution, (0.25 N):

Dissolve 12.2588 g of $K_2Cr_2O_7$, primary standard grade, previously dried for 2 hours at 103°C in water and dilute to 1000 mL.

Standard ferrous ammonium sulfate, 0.25 N:

Dissolve 98 g of $Fe(NH_4)_2(SO_4)_2\,6\,H_2O$ in distilled water. Add 20 mL of conc. H_2SO_4, (6.7), cool and dilute to 1 liter. This solution must be standardized against the standard potassium dichromate solution.

Standardization:

Dilute 10 mL of standard dichromate solution to about 250 mL with distilled water. Add 20 mL conc. sulfuric acid. Cool, then titrate with ferrous ammonium sulfate titrant, using 3 drops of ferroin indicator.

$$Normality = \frac{[(mL\mathrm{K_2Cr_2O_7})(0.25)]}{[mL\mathrm{Fe(NH_4)_2(SO_4)_2}]}$$

For Chemical Oxygen Demand:

i) Take 1 mL of the sample into a round bottomed flask. Place a small porcelain piece and add 25 mL of Potassium dichromate ($K_2Cr_2O_7$) solution. 15 mL Silver Sulfate- Sulfuric acid solution is slowly added to the flask solution.

ii) Digest the contents in the flask using a hot plate (or bunsen burner) for 1.5 hours.

iii) After the reflux time is over, cool the flask, rinse the condenser with 25 mL of distilled water and collect the rinsing's in the same flask.

iv) Add 2-4 drops of ferroin indicator to the flask and titrate with 0.25 M Ferrous Ammonium Sulfate solution to the endpoint (VS).

v) Prepare a blank in the same manner as sample using distilled water instead of the sample (VB).

vi) Calculate the chemical oxygen demand by following formula:
COD = 8 x 1000 x M x (VB - VS)
where, M – Molarity of FAS

Problems related to colour in waste water

A dyebath is never exhausted completely of colour. Unexhausted colour, whether water soluble or not, imposes negative effect on water body when drained. Most of the colours have compact structure with high organic content and are applied in soluble condition.

On draining, these are spread over the water body, do not allow sunlight to pass through and deprive the stream of its dissolved oxygen. The asphyxial point for trout at 10°C is approximately 1.5 ppm of dissolved oxygen; for coarse fish this may be as low as 0.5 ppm. For every 10°C rise in temperature, a stream fish requires an approximately two-fold increase in dissolved oxygen and maximum oxygen that can be dissolved by water at 20°C water is about 9 mg/l.

The primary effects produced by various colours on receiving streams are:

i) toxicity to stream life - which is not only destructive to fish and aquatic life of that charter, but has effect of killing bacteria and various other forms of biological life upon which stream self-purification processes depend, with the result that the development of fish life is prevented

ii) oxygen depletion in stream water - on complete consumption of dissolved oxygen, putrefaction sets in and a septic condition is created.

Removal of colour can be affected in various ways:

i) *Chlorination:* the cheapest and simplest method. Hypochlorite bleaching has also the same effect. But it has several limitations, viz. if the final effluent goes into a watercourse from which water for domestic consumption is drawn, chlorination should not be done in presence of tar acids, because chlorophenols are highly resistant to bacterial oxidation. Noxious odour of chlorine poisons surrounding air.

ii) *Chemical coagulation:* most effective and economical method, even suitable for most of the dyes. Popular coagulants are lime, alum and iron salts – used alone or in combination; a dose of 300–600 mg/l removes around 75–90% of colour from dye effluent. Coagulation method uses action of chemical adsorption or bonding to separate dissolved contaminants from effluents. This method has two drawbacks: (a) it is time consuming – special tests are required to establish which coagulating agent or combination of agents effective for each type of effluents and (b) produces sludge – different coagulant produces different amount of sludge.

Coagulants neutralize the negative electrical charge on particles, which destabilizes the forces keeping colloids apart. Water treatment coagulants are comprised of positively charged molecules that, when added to the water and mixed, accomplish this charge neutralization.

Coagulation are used to separate the suspended solids portion from the water. The suspended particles vary considerably in source, composition charge, particle size, shape, and density. Correct application of coagulation and flocculation processes and selection of the coagulants depend upon understanding the interaction between these factors. The small particles are stabilized (kept in suspension) by the action of physical forces on the particles themselves. One of the forces playing a dominant role in stabilization results from the surface charge present on the particles. Most solids suspended in water possess a negative charge and, since they have the same type of surface charge, repel each other when they come close together. Therefore, they will remain in suspension rather than clump together and settle out of the water.]

iii) *Biological oxidation:*

colour removal is done by activated sludge method, primarily by flocculation or adsorption of dyes by microorganisms. But in many instances, most colours simply pass through the activated sludge process unaffected regardless of how the treatment system is operated.

iv) *Adsorption*

It is an efficient and popular method of colour removal. Several adsorbents are known to be capable of removing dyes from textile effluent. These include activated carbon, saw dust, fullers earth, fly ash, fired clay, baggasse pith, wood, peat etc. The pH must be adjusted to near neutral and suspended particulates must be removed for adsorption unit to function properly.

Activated carbon adsorption: two forms of activated carbons are used in waste water treatment, viz. granular and powdered. The powder form is utilized mainly in conjunction with the activated sludge process.

Conventionally, adsorption processes using activated carbons are widely used to remove colour and heavy metal pollutants from wastewaters. However, commercially available activated carbon is becoming too expensive. In the last few years, special emphasis has been placed on the preparation of activated carbons from several agricultural by-products due to the growing interest in low-cost activated carbons from renewable sources, especially for application in wastewater treatment. Researchers have studied the production of activated carbon from sugar beet bagasse, apricot shell, sun flower seed hull coconut shells, rubber seed coat, oil palm fiber , rattan , date stones , plum kernels and palm empty fruit bunch and bamboo.

(Adsorption is a surface phenomenon that is characterized by the concentration of a chemical species (adsorbate) from its vapor phase or from a solution onto or near the surfaces or pores of a solid (adsorbent). This surface excess occurs in general when the attractive energy of a substance with the solid surface (i.e., the adhesive work) is greater than the cohesive energy of the substance itself. The adsorptive uptake is amplified if the solid material has a high surface area. If the adsorption occurs by London–van der Waals forces of the solid and adsorbate, it is called physical adsorption. If the forces leading to adsorption are related to chemical bonding forces, the adsorption is referred to as chemisorption.)

v) *Chemical Oxidation:*

this is done by using chlorine, ozone or H2O2 . Effect of ozone is twice than that of chlorine, because it is unstable – having a half-life of only several minutes. Problem is that it cannot be transported and must be generated on-site from air or oxygen. Except insoluble azoics and disperse dyes, other colours and odours can be completely removed through this technique.

vi) *Reverse osmosis and ultra-filtration:*

these are pressure driven membrane processes. The modern methods are based on flat membrane sheets in arrangements similar to that of a plate and frame filter process.

Supplementary readings and references of significance

Abstract 1.

Reduction of COD and color of dyeing effluent from a cotton textile mill by adsorption onto bamboo-based activated carbon

lA.A.Ahmad B.H.Hameed

ABSTRACT

In this paper dyeing waste water was simulated by using reactive brilliant blue XBR (an anthraquinone dye). Activated carbon adsorption process, coagulation process and chemical oxidation process were used to treat dyeing waste water. In activated carbon adsorption process and coagulation process, the water absorbance values were measured. The COD value of water was determined in Fenton chemical oxidation process. Then, the decolorization rate and COD removal rate were calculated respectively. The results showed that the optimum conditions of activated carbon adsorption process were as follows: pH=2, the dosage of activated carbon was 1.2g/L, the adsorption reaction time was 60 min, and the average decolorization rate of the three parallel experiments was 85.30%. The optimum conditions of coagulation experiment were as follows: pH=8 9, PAC dosage was 70mg/L, stirring time was 20min, standing time was 45min, the average decolorization rate of the three parallel experiments was 74.48%. The optimum conditions for Fenton oxidation were $Fe_2{}^+$ 0.05g/L, H_2O_2 (30%) 14mL/L, pH=3, reaction time 40min. The average COD removal rate was 69.35% in three parallel experiments. It can be seen that in the three methods the activated carbon adsorption treatment of dyeing wastewater was the best one.

Abstract 2

Wastewater Treatment by Coagulation Process: Review Paper

Ms Apeksha Awasthi Dr. Parag Dalal , Dr. J. K. Srivastava

ABSTRACT

Dyeing and printing industries process outcome is one of the most common environmental unfriendly process. The heavy toxic chemicals are generally used for dying and printing process. The large amount of raw water is been used in this colorization process. This paper deals with the dye wastewater which is collected from Bhairavgarh area of Ujjain (M.P.) with the help of coagulation process. Some of the dyeing industries use the inorganic chemicals in the process of dyeing the textile. Bhairavgarh dyeing industry is one of them. This paper investigate the chemical contamination in the sampled collected wastewater with the use of coagulation process to measure the physical parameters such as pH, BOD, COD, DO, TDS, SS etc. It also shows a comparative study of parameters of the wastewater before and after the coagulation process implementation.

Keywords: Dye industry, Colorization, Coagulation, Bhairavgarh, Physical Parameters, and Wastewater.

Abstract-3

Assessment Of Sawdust Potential In The Removal of Dye Colour From Textile Wastewater

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ABSTRACT

The potential of hardwood and softwood sawdust as low cost adsorbents in the removal of a disazo dye (Congo Red) from water was evaluated. Two softwoods, Cypress (Cypressus lusitanica) and Pine (Pinus spp.) and two hardwoods Camphor (Ocotea usambarebsis), and Meru oak (Vitex keniensis) were used in the studies. Those materials were selected on the basis of their relative abundance as a waste in the timber mills industry. Sawdust was found to have potential in removing Congo red dye from wastewater. The interaction of dye and the sawdust conform to Freundlich adsorption model with softwoods showing a higher potential both in capacity and intensity of removing Congo red dye from wastewater than hardwoods. The coefficients of Freundlich equilibrium model, k and n show that Cypress (Cypressus lusitanica) had the highest potential having k and n values of 0.40 and 1.79, respectively, followed Pine (Pinus spp.) with k and n values of 0.33 and 1.05, while Meru oak and Camphor had the two values being 0.23 and 0.823, and 0.0069 and 0.619, respectively. The higher dye uptake by softwood sawdust is attributable to more pore spaces and high specific surface area for adsorption than hardwood. The softwoods had lower densities than hardwoods and thus the far more porous. The adsorption correlated positively with the hemicellulose extract of the sawdust, which was high in cypress, pine, Meru oak, and Camphor in that order. Cellulose and lignin content correlated negatively with the adsorption capacity and intensity.

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Calculations for preparation of stock solution

For Temperature between 60°-70°,

Quantities Required,

Quantity of Dye	Quantity of 40 % Caustic stock	Hyposulphite
1gm	8-10cc	2gm
0.25gm	2-2.5cc	0.5gm
For Blank VAT(500ml),		
0	10cc/lit	10g/lit
	5cc/500ml	5g/500ml

Calculation for volume of dye solution to be taken for % shade

Volume of dye solution to be pipetted out = $\frac{\text{\% shade required} \times \text{weight of material(yarn)}}{\text{concentration of stock dye solution}}$

Material : liquor ratio for 2% shade,

M : L = 1gm : 30ml

Dye pot solution contains

- Dye solution as per calculation
- Caustic 40% as given in table **??**,
- Blank VAT to make up the quantity to M:L ratio

Precautions

1. Check the concentration of caustic solution with VAT yellow paper or phenolphthalein
2. After every 2 minutes rotate the hank
3. Keep the hank for air oxidation after dyeing
4. Neutralize with acetic acid and wash with cold water

Example of calculation

Weight of hank = $2.2gm$

Dye Solution = $\frac{2\times2.2}{0.25} = 4.4 \times 4 = 17.6ml$

Caustic Soda = $2.5ml$

Hyposulphite = $0.5gm$

Blank VAT = $9ml$

M : L = 1 : 30 = 2.2 : 66

Blank VAT = $66 - 20.6 = 45ml$

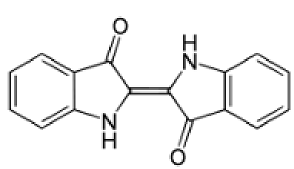
Appendix G: Indigo lab task sheet

This module presented here relates to the waste water generated through the dyeing of indigo.

Indigo Dye

Colours and dyeing of fabric are almost as old as civilization. One of the dyes known since a very long time is indigo. India was one of the major world cultivators of indigo plant, a natural source for indigo dye. Extraction of Indigo dye from plants involves fermenting the leaves overnight followed by treatment of the filtrate with an enzyme, indimulsin, to hydrolyze and form indoxyl. Indoxyl on further air oxidation gives the required indigo dye. Indigo also has an interesting history related to British India. On one hand exploitation of the Indigo planters started Bengal revolt, on the other hand, to end the monopoly of British in indigo extraction and commerce, German scientists (Von Baeyer) started researching to understand the chemical nature and the ways and means for commercial production of this dye.

Later, chemical synthesis of this dye was undertaken in a large scale, especially with the popularity of Levi's brand of jeans close to the end of eighteenth century.



Formula: $C_{16}H_{10}N_2O_2$, Molecular weight: 262.27 g/mol, Melting point : 390°C.
(Ref: https://sites.google.com/site/kateannelong/thechemicalera)

Problem to Investigate
We conducted trials for vat dyeing of indigo colour in chemistry laboratory of HBCSE using procedure given in one of the references given to you. The waste water from these trials cannot be disposed off as such into the sink. You are one of the member of the team who is authorised to suggest the treatment plan for safe disposal of this waste water. Your recommendations should be forwarded as a report to HBCSE.

Module Objective:

To plan and carry out waste-water analysis and treatment

To collect data to optimise treatment method

To write a report on the task carried out

Prelab task

Q1: What information do we need to know? (Identify what information related to the task is known and what is to be acquired). (15Min.)

What information we know	What information we need to know/gather

Q2. Make a choice of the parameters that you may want to analyse and treat?

Parameter	Reason for choosing

Here is the list of available chemicals equipments and glassware.

Glassware	Volume	Quantities required
Beaker	100mL	
Beaker	250 mL	
Conical flask	100 mL	
Conical flask	250 mL	
Round bottom flask	250mL	
Measuring cylinder	10 mL	
Measuring cylinder	100 mL	
Porcelien	dish	-
Glass rod	-	
standard flask	100 mL	
condenser	12 inch	
Burette	50 ml	
pipette	10mL	25 mL
droppers	-	
Glass beads		

Chemicals

Chemicals	Quantities required	Safety symbols
Ferrous ammonium sulphate		
Potassium dichormate		
Conc.Sulphuric acid		
Silver sulphate		
ferroin		
Liquid alum		
Activated charcoal		
Acetic Acid		
Saw dust		

Q3.Give detailed plan of the task? Your plan should include the following.

a) steps you would follow

b) waste water quantity that you would take for analysis

c) quantity of the chemicals you would consume

d) A flow diagram of your plan

Q7. What safety measure will you take?

Lab trials (Present your trials in a tabulated form).

Data table for waste water treatment

Parameters	Permissible limits	Values before treatment(if any)	Values after treatment(if any)

Write the steps involved in the analysis of COD and mention the purpose of each of those steps.

Step	Purpose

Table G.1: Purpose of COD

Phase IV

Q1. Write the report and suggest recommendation that need to be followed at HBCSE chemistry laboratory.

Your report should include answers to the following questions.

1. What are my questions ?
2. What did I do?
3. What did I observe?
4. What can I conclude?
5. How do I know? Why am I making these conclusions ?
6. What do I recommend?

Appendix H: LRP pointers for writing lab reports

B.Sc. (Blended)	Semester-
Name:	
Experiment No.	Date of Experiment:
	Submission date:

Title

Aim

Apparatus

Chemicals

Theory

Hypothesis/Questions

Procedure

Flow chart of the procedure

Observations

Qualitative

Quantitative

Results and Discussion

References

Appendix I: Rubric for assessment of ED of the indigo PBL task

Descriptor	0 point	1 point	1 point	1 point	1 point	Max. /4
Parameters chosen for analysis	None	pH	COD	Suspended Solids	colour	
Treatment chosen	None	for pH	for COD	for Suspended Solid	for colour	
Executable plan (feasibility in an undergraduate lab)	Not executable	Available time (3 lab sessions)	Available equipment	Available Chemicals /substances	Available glassware	

Descriptor	0 point	1 point	1 point	1 point	1 point	Max. /4
Quantities / Concentration	Not mentioned	Quantity of wastewater	Quantities for chosen treatment method	COD (quantities of chemicals)	COD Concentrations of chemicals)	
Optimization	None considered	Amount of AC/Saw dust/ Coagulant	Treatment condition pH/ temperature	Time for equilibration of AC/saw dust/ or coagulant	Minimally two trials	
Flow-chart	Not presented	pre- treatment Analysis	Treatment after initial analysis	Post- treatment analysis	Clarity of representation	
Tools for Measurement	None indicated	pH meter /pH paper	Glassware and indicator for COD	Weighing balance	Colorimeter / visual comparison	

Appendix J: Rubric for assessment of LRP laboratory report

Description	Components	Scores
RQ/Hy/Obj	Clear, comprehensive, testable	3
	Clear, testable, factors not mentioned	2
	Not clear/ not testable	1
	Not mentioned	0

Description	Components	Scores
Experimental procedure	Addresses the question/ Novelty	3
	Analysis and treatment mentioned	2
	Vague procedure	1
	Not mentioned	0

Description	Components	Scores
Result	3 observations mentioned related to the questions	3
	2 observations mentioned	2
	1 observation mentioned	1
	Not mentioned	0

Description	Components	Scores
Conclusion	Addresses the question, Based on the data, evidence	3
	Based on the data	2
	Some gap in the above two (not clear)	1
	Not mentioned	0

Description	Components	Scores
Explanations	Offered for the observations and conclusion	2
	Not logical connection/not clear	1
	Not mentioned	0

Description	Components	Scores
Writing strategy	Clear, logical progression, easy to read	2
	Not easy to read	1
	No clarity/haphazard	0

Appendix K: Questionnaire indigo lab

Q1. What helped you the most in planning and executing the task? Why?

Q2.The following methods/materials were used to support the PBL task. Put a tick mark on the column that you may find the most appropriate.

Description	Most useful	Somewhat useful	Useful	Not useful	Cannot say
Precursor					
Reading material					
Group Discussion					
Lab task sheet					
Pointers for writing the report					
Facilitators guidance					

Q3. Give a ranking from 1-6 depending on the usefulness of these descriptors in completing the task. Rank 1 means most helpful, and rank 6 means less useful than the other descriptors.

Descriptor	Rank 1^{st} to 5th	Reason for the choice of the first rank over the others
Processor		
Reading material		
Group Discussion		
Lab task sheet		
Pointers for writing the report		
Facilitators guidance		

Q4. Write your experiences with the interaction/discussion that you have hadQ5. The following section gives some description of how you executed the module. You must put a tick mark on the descriptors that indicate your viewpoint/perception about the module and its execution.

Put a tick mark on whichever box is applicable.

Reading material and planning

The selection of information in the reading material was	Easy	Moderately difficult	Challenging
Comprehension of the reading material was	Easy	Moderately difficult	Challenging
Making a plan based on the reading material was	Easy	Moderately difficult	Challenging
Content in the reading material is related to my existing chemistry knowledge	To a lesser extent	To some extent	substantially
The reading material provides new information	To a lesser extent	To some extent	substantially

Problem-Solving

Indicates your opinion about how you planned to arrive at the conclusions.

The task	Involved less thinking	Involved moderate thinking	Thinking through the task was challenging
Identification of necessary information	Easy	Moderately difficult	challenging
Planning of the task	Easy	Moderately difficult	challenging
Use of selected information from the literature	Not effective	Moderately effective	Effective
Execution of the task was	Easy	Moderately difficult	Challenging
Solving the problem was	Easy	Moderately difficult	Challenging

Group work

In the following table, indicate your opinion about the work done by you and your group members as a group.

Interaction among all members	Less frequently	Frequently	Continuously
Overall Contribution	One member dominates	Most have contributed	All have contributed
Progress as a group	Little progress	Moderate progress	Steady progress
Prelab contribution of group members	Good	Moderate	Very good
Lab-work	Contribution of group members	Good Moderate	Very good
Post-lab contribution of group members	Good	Moderate	Very good