Problem-Based Learning in Undergraduate Chemistry Laboratories in India

A Synopsis of the Ph.D. Thesis

Submitted in the partial fulfillment of the academic requirements for the degree of Doctor of Philosophy in Science Education

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Contents

Abstract
Publications
Conference Presentations
Introduction and Organization of the Thesis

Chapter 1 Literature Review
1.1 Roles and Goals of Undergraduate Chemistry Laboratory Education
1.2 Instructional Styles in the Undergraduate Chemistry Laboratory
1.2.1 Expository instructional Style
1.2.2 Inquiry instructional style
1.2.3 Discovery Learning
1.2.4 Problem-Based learning style
1.2.5 POGIL(Process Oriented Guided Inquiry Learning)
1.3 Rational for Choosing Problem-Based Learning Style

Chapter 2 Indian Context
2.1 Analysis of lab manual(Pune and Mumbai Region)
2.2 Interview of two authors
2.3 Teachers and students' perception of the goals of chemistry lab education
2.4 Introduction of inquiry in the undergraduate lab: A pilot study

Chapter 3 Conceptual and Theoretical Framework
3.1 Conceptual Framework
3.1.1 Inquiry instruction
3.1.2 PBL instruction
3.1.3 Role of problem
3.1.4 Role of facilitator
3.1.5 Role of students
3.2 PBL and learning theories
3.3 Learning models on PBL
3.4 Factors leading to ineffective implementation of PBL
3.5 Scaffolding for success

Chapter 4 Development of Indigo Lab Course
4.1 Design principles
4.2 Instructional principles
4.3 Design of scaffolds

Chapter 5 Research Methodology
5.1 Research Questions
5.2 Study-1: Role of scaffolds in devising an experimental design
5.2.1 Methods
5.2.2 Participants
5.2.3 Research Design
5.3 Study-2: Case study on the implementation of a short course with incremental inquiry levels
5.3.1 Methods
5.3.2 Research Design
5.3.3 Data Analysis
5.4 Validity and reliability aspects of the research
5.5 Instruments for evaluation of experimental Design

Chapter 6 Analysis of Data from Study 1
6.1 Results from Quasi-experimental study on scaffolds
6.1.1 Scaffolded and un-scaffolded groups
6.1.2 Two scaffolds vs three scaffolds
6.1.3 Scaffolds in Institute and Authentic settings
6.1.4 Student's perception of scaffolds
6.2 Analysis of individual scaffolds in the Authentic setting
6.2.1 Precursor task
6.2.2 Reading material
6.2.3 Group discussion
6.3 External observers' remarks

Chapter 7 Analysis of Data from Study 2
7.1 Results from Case Study on science practice skills
7.1.1 Hypothesis
7.1.2 Experimental design
7.1.3 Discussion
7.1.4 Lab reports

Chapter 8 Conclusion
8.1 Summary of the Research Study
8.1.1 The results from study-1
8.1.2 The result from study-2
8.2 Limitations
8.3 Future Directions
8.4 Implications of the study
8.4.1 For researcher
8.4.2 for curriculum designer
8.4.3 for practitioners

References
Appendix I Questionnaire

Problem-Based Learning in Undergraduate Chemistry Laboratories in India

Abstract

My research study explored the feasibility of implementing inquiry-based approaches in Undergraduate Chemistry Laboratories in colleges affiliated with the university system in India. The two premises at the start of my study were, a) there is a need to present a holistic approach to laboratory experience by integrating different domains of chemistry and, b) it is important to provide adequate time to the learner for engagement with the inquiry-based tasks to learn the process of inquiry.

I went through the CER literature to understand what the researchers think of as the goals of laboratory learning. Further, a survey was carried out to understand the teachers' and students' perceptions of the goals. To extend my understanding, I analyzed two representative laboratory manuals to infer the kind of instructional style adopted by the colleges in the region where my study is situated. Additionally, a pilot study was conducted to check the feasibility of implementing inquiry in the laboratory. On the basis of all this learning, I designed a short inquiry-based course on Indigo Dye. It adopted, a) an incremental approach to introducing inquiry-based modules and b) a scaffolded approach to introduce Problem-Based Learning (PBL).

My research study had two components. The first one explored the role of scaffolds in helping learners devise the Experimental Design (ED) in a PBL environment. This study was conducted at HBCSE, TIFR, and in the authentic setting of a students' college. The second component of the study explored the implementation of the short course which, a) integrates different domain of chemistry, b) introduces inquiry in an incremental manner, and c) covers PBL experimental module as a higher level of inquiry. This study has been conducted in an authentic setting as a case study spread over a longer duration of four months. I tried to understand the Science Practice Skills gained through the course with four sequential experiments. Both studies have been conducted with first-year undergraduate students.

Our results indicate that the incremental approach is a promising way to transit students from conventional to inquiry-based labs and it enhances the science practice skills of students. Additionally, for PBL-based experimental modules, scaffolds play a crucial role to develop meaningful experimental designs.

Publications

1. Varadarajan, S. and Ladage. S. (2021), Adapting an Inquiry-Based Approach for Undergraduate Chemistry Laboratory: An exploratory study, *Current Science*, 121(3) p.0354 DOI: 10.18520/cs/v121/i3/354-359

2. Varadarajan, S. and Ladage. S. (2021), Exploring the Role of Scaffolds in Problem-Based Learning(PBL) in an Undergraduate Laboratory, *Chemistry Education Research and Practice*, DOI: 10.1039/D1RP00180A.

3. Varadarajan, S., & Ladage, S. (2022). Introducing Incremental Levels of Inquiry in an Undergraduate Chemistry Laboratory: A Case Study on a Short Lab Course. *Journal of Chemical Education*. https://doi.org/10.1021/acs.jchemed.2c00297

Conference presentations :

- X-Discipline Nebraska Lincoln University, USA**. *Scaffolding Problem-Based Learning in Undergraduate Laboratories*** (Oral presentation), March 1-3, 2021.
- International Union for Pure and Applied Chemistry │ Canadian Chemistry Conference and Exhibition (IUPAC |CCCE) 2021**:** organized by Congress Organizing Committee, Canada. ***Problem-Based Learning: Life-cycle thinking approach to Indigo-dye lab,*** August 13 to 20, 2021. (Co-author: Savita Ladage).
- ChemCollective workshop on Virtual Laboratory, organized by IIT-Bombay, ***Science Skills through Chemical Laboratories,*** for CBSE school teachers across pan India (around 250), June 17, 2021.
- ECRICE-2020 Conference, organized by Weizmann Institute of Science. Israel ***Exploring the Role of Scaffolds in Mediating Reflective Thinking: Problem-based learning in an undergraduate chemistry laboratory*****.**
- Methods in Chemistry Education Research (MICER) 2020, organized by Edinburgh University, UK. ***Assessing Small-group Learning in a PBL Undergraduate Chemistry Laboratory,*** MICER 2020, UK.

Introduction and Organization of the Thesis

Chemistry Education Research (CER) literature describes the goals of laboratory education as, helping students engage in cognitive, affective, and psychomotor aspects of experimental work The literature on chemistry lab education emphasizes the use of inquiry-based approaches and has suggested various inquiry instructional styles. An inquiry-based approach helps students to become independent investigators and engages them in higher-order thinking.

The CER studies acknowledge both the merits and the difficulties/challenges faced while adapting inquiry-based approaches. The educational context may be diverse and thus, raises the need for a dedicated research-based approach to meet the challenges at the local level. Today, when state colleges in India are getting academic autonomy and teachers are becoming more open to shifting from conventional pedagogical practices and the content, such studies are the need of the hour for the shift that is recommended in the literature for engaging students in higher order thinking skills. To the best of my knowledge, sparse work of this kind exists in the Indian context.

The research work is elaborated in this thesis in eight Chapters. The first Chapter presents the literature review to understand the goals of the laboratory and various instructional styles adopted in the undergraduate chemistry laboratory as described in the CER literature. The second Chapter describes the present status of chemistry laboratory education by analyzing the prescribed laboratory manual used in state colleges of Pune and Mumbai (affiliated with the universities) in Maharashtra, India where my study is located. This Chapter also presents the goals that the teachers (n =36) and students (n =58) consider as the most preferable through the analysis of a survey questionnaire. Additionally, to understand the feasibility of introducing inquiry in the undergraduate chemistry laboratory, the results from a pilot study is given in this Chapter 2. This study provides a basis for considering the development of inquiry-based and problem-based modules for chemistry laboratory education for state colleges in India. Chapter 3 discusses the conceptual and theoretical framework related to inquiry-based pedagogy with a focus on problem-based learning. The conceptualization and detailed description of the design and development of the short course is presented in Chapter 4. Aspects such as research design, development of instruments, validity, and reliability are discussed under the research methodology, that is, in Chapter 5. Chapter 6 presents the results from the study related to the scaffoldings required to implement a PBL task in the laboratory. Chapter 7 describes the results from the implementation of the Indigo inquiry module in the authentic setting of a college as a short course with incremental levels of inquiry. The last Chapter 8 on conclusion summarises the study, its findings, limitations, and future direction. It also describes the possible implication of the study for curriculum designers, researchers, and for practitioners.

Chapter 1. Literature review

1.1 Role and Goals of Undergraduate Laboratory Education

It is important to understand what goals are set for chemistry laboratory education as students spend significant time (~300 hours in all) in the labs during the three years of undergraduate education (Bruck & Towns, 2009; Hofstein & Mamlok-Naaman, 2007; Reid & Shah, 2007). Thus, the researchers have tried to answer the question, "why do we have chemistry laboratory work in the curriculum?"(Seery, 2020). It is important to articulate and communicate the goals and aims of laboratory education to the students, curriculum designers, and, teachers (Boud and Hazel, 1989). The researchers claim that, if the students know the goals in advance, it enhances their chances of meeting objectives (Kirchner, Meester 1988.). Additionally, the goals of the curriculum should be well aligned with what the teachers think as the goals and with the expectations of the students to reach the desired learning outcomes.

With much deliberation, the overall goals have been identified in CER literature in terms of, a) cognitive, b) affective, and c) psychomotor aspects. These goals are based on what Novak describes as meaningful learning which can be attained depending on the prior knowledge of the learner, suitable curricular material, and the learners' disposition to integrate the new knowledge (Bruck and Towns 2013). Seery (2020) contends that the laboratory space need not be used to support the lecture content or to develop soft skills such as teamwork, time management, etc., rather the laboratory work should help the student to develop an understanding of *how to do* the chemistry and get a sense of chemist's identity. Table 1.1 presents a compiled list of learning goals as suggested in the CER literature. The overall goals can further be categorized as given in this table.

Table 1.1 Goals of the Undergraduate Chemistry Laboratory

Learning goals	Subcategories of the goals
Cognitive	Overall learning goals
	Epistemic goals
	Chemistry content-specific goals
	Scientific skills
Affective	Affective goals
	General skills
Psychomotor domain	Practical skills

The lab curricula and the instruction styles with these learning goals are expected to give holistic learning experiences to students.

The instructional styles proposed to achieve these goals are classified by Domin (1999a) as expository, discovery, problem-based, and inquiry-based. The following section describes these styles briefly to understand what goals could be achieved by adopting a particular style.

1.2 Instructional Styles in the Undergraduate Chemistry Laboratory

1.2.1 Expository instructional style is a deductive approach where the students are given the procedure to be followed stepwise to reach a result that is predetermined and known to both the student and the instructor. The purpose of such lab education is the verification of a particular concept. It can be useful in the development of hands-on laboratory skills, cater to large class sizes, and requires lesser time to complete. It often demands low cognitive engagement and does not expose students to the nature of scientific experimentation (Dunlap and Martin, 2012; Ault, 2002; Domin 1999).

1.2.2 Inquiry instructional styles It mimics the thinking process of scientists and helps students to go through the steps such as a) formulating a hypothesis, b) designing an experiment, c) collecting, and interpreting the data, and d) presentation of results in a scientifically accepted format.

There are different kinds of inquiry instructional styles characterized by the amount of information shared with the students and whether the outcome is known to the students or the instructors.

1.2.3 Discovery Learning engages students in the inquiry process in which students are expected to discover the concept through the given procedure. The students are not aware of the outcome though the instructors know it. However, this method neglects the need for prior knowledge and there is a good possibility that the concept which is expected to be discovered is not discovered by students (Dunlap and Martin, 2020; Domin 1999)

1.2.4 Problem-based learning style is one of the good options for an inquiry approach where the students are given a problem statement and, while working at it, they learn the requisite concepts and acquire knowledge. Both the content and process become equally important in this pedagogical style. Students focus on a testable hypothesis rather than a correct result expected at the end of the lab work (Eilks and Byers, 2009; White 2002, Duch et al. 2001).

1.2.5 POGIL (Process Oriented Guided Inquiry Learning) approach is quite popular as this instruction provides students guiding questions in the direction of the expected outcome to help them go through the inductive deductive cycles to recognize the pattern and discover a concept (Daubenmire & Bunce, 2008; Latimer et al., 2018; Moog et al., 2006; Reynders et al., 2019; Rodriguez et al., 2020).

Bruck et al. (2008) classify the inquiry levels of the inquiry tasks from level 0 to level 3. Level 0 corresponds to confirmatory/verification lab, level 1 to structured inquiry (students precisely follow the steps of the given procedure), and level 2 is guided inquiry where students' inquiry is guided through multiple means such as cueing questions, prompts, etc. whereas the level-3 inquiry is authentic inquiry where the outcomes are not known to either the student or the instructor. Level-3 instructional style, in my opinion, poses a challenge to the instructor in making available all of the required resources (glassware, equipment, chemicals, etc). needed by the students and thus may not be feasible for a large undergraduate class even though it adheres to the practices of authentic scientific investigation.

1.3 Rationale for Choosing Problem-Based learning as the Instructional style

Several researchers have extensively studied the PBL learning pedagogy in the chemistry laboratory to understand the cognitive, and affective dimensions and the challenges in the implementation. Literature suggests that the results from such studies on PBL in chemistry laboratories are encouraging in terms of meeting both the cognitive and affective goals of the laboratory. PBL pedagogies in general are advantageous in developing science practice skills and in self-efficacy beliefs (Costantino & Barlocco, 2019; Gurses et al., 2007; Kelly & Finlayson, 2007; Mc Donnell et al., 2007; Shultz & Li, 2016; Smith, 2012; Wellhöfer & Lühken, 2022).

The literature suggests that there are challenges in the implementation of PBL. However, these could be overcome by a heterogeneous grouping of students who are engaged in cooperative learning. Though successful PBL needs students to take ownership of their learning, teamwork seems to be providing the necessary support for students to navigate through the problem (Tosun & Taskesenligil, 2013). Students found PBL instruction relevant, and enjoyable and can remain motivated if the given problem is engaging enough. Development of metacognitive skills and problem-solving skills are claimed to improve with PBL (Sandi-Urena et al., 2012). Thus, CER literature indicates that PBL is a promising approach.

I planned to study an incremental approach to inquiry starting from structured inquiry to problem-based learning (PBL) to help students gradually go through the inquiry process with both content and the process in focus. I believe that this approach offers better pedagogical feasibility for introducing inquiry to students from a conventional laboratory. Real-life problem-solving leads students to construct new knowledge and remain motivated. In PBL, the prerequisites for problem-solving are provided to the students and any gap is filled through collaborative learning and interaction with the facilitator (Kelly & Finlayson, 2007; Sandi-Urena et al., 2011).

Chapter 2. Indian Context

2.1 Analysis of lab Manuals (Mumbai and Pune region)

To get a sense of the instructional style followed, I studied the representative lab manuals used in colleges affiliated with Savitribai Phule Pune University (SPPU) and Mumbai University, since participants for my study were first-year undergraduates from the Pune and Mumbai regions. There are around 1500 colleges affiliated with both these universities and the colleges strictly follow the syllabus prescribed by the universities.

Lab manuals have been analyzed by researchers in the past based on cognitive engagement possible by following the given instruction given (Bopegedera, 2011; Bruck et al., 2008; Domin, 1999). In a similar attempt, I analyzed the manuals for the overall content, presentation of the experimental procedure, and the range of experiments covered in different domains of chemistry. I observed that the lab manuals do not state the learning objectives either in the preface or at the beginning of the individual experimental write-up. The description of the experiment state the following; aim of the experiment, brief theory, glassware/chemicals, procedure, data tables, and conclusion suggesting the approach to be the conventional style.

The syllabus has included experiments needing lesser resources and the emphasis is on the development of hands-on lab skills. The same type of experiment is performed several times and each experiment is a standalone experiment.

The physical chemistry domain covers a larger spectrum of experiments as compared to inorganic and organic domains. Analytical chemistry is less represented through experiments.

In terms of concepts and techniques, titrimetric analysis is the most dominant area of experiments (50% and 71% Pune and Mumbai lab manuals respectively) for all the 3 years of the undergraduate lab course. The plausible reasons could be the titrimetric technique does not need expensive glassware and encompasses different kinds of titrations such as acid-base, redox, complexometric, etc. It is relatively easy to perform and has well-established protocols for quantitative estimation.

The total number of experiments for all three years is 119 in the SPPU-prescribed syllabus/manual. The percentage of context-based experiments is about 20 and that using the green chemistry approach is 1%. The inquiry-based approach is not a part of any experiment and thus the experiments in the manual are at level 0 of inquiry-based learning. For the Mumbai region, the percentage of context-based experiments is 15% and no experiment uses a green chemistry approach. Again, the inquiry-based approach is not included any of the 108 experiments described in the syllabus prescribed by Mumbai University.

2.2. Interview of two authors of lab manual (Pune region)

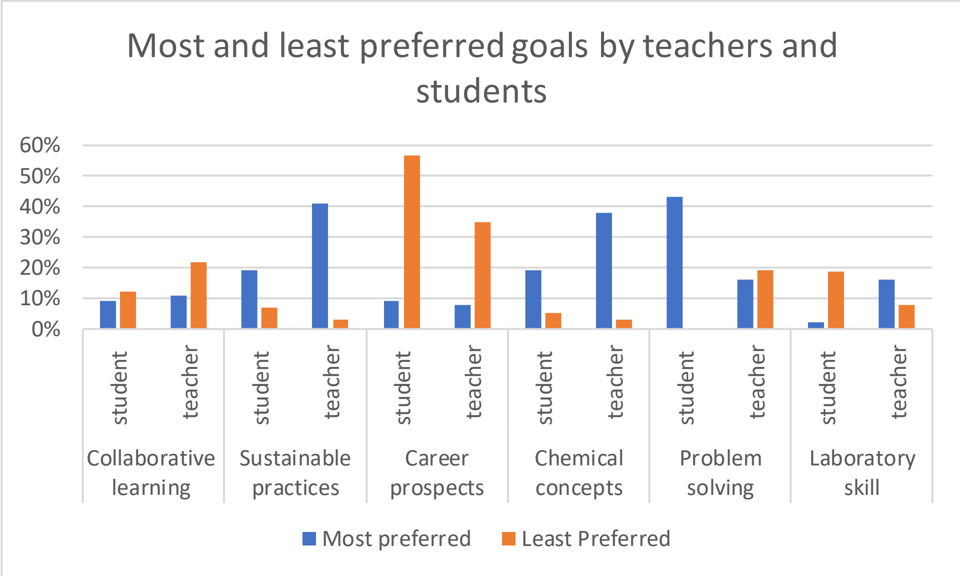
The interviews with two authors of the manuals for state colleges affiliated with SPPU suggests that often revisions of manual involve making the procedures simpler rather than changing the instructional type drastically. One of the authors suggested, though the objectives are not mentioned in the manuals, these are expected to be communicated in the classroom. According to him, theoretical/conceptual understanding and imparting practical skills are the two important objectives of laboratory instruction. The website of SPPU University further triangulates these ideas where the stated learning objectives are towards developing skills related to a specific concept (F.Y.B.Sc. Chemistry_19.062019.pdf (unipune.ac.in).

2.3 Teachers' and students' perceptions of the goals of lab education

A rank-order survey questionnaire was administered to 37 chemistry teachers from various colleges across Maharashtra and 58 students belonging to colleges all across India to understand their perceptions about the goal of chemistry laboratory education. The questionnaire contained six goal-statements to be prioritized and ranked accordingly.

The frequency of the statement with ranks 1 to 6 was calculated. The results are presented in Fig. 2.1 which gives the most preferred and the least preferred statements based on the maximum and minimum frequency of each of the statements chosen by the teachers and the students.

Figure 2.1 Most and least preferred goals by teachers and students



Problem-solving was chosen as the most preferred statement of goal by 43% of students and they considered career goals as the least preferred objective. Contrasting this, only 16% of teachers have selected problem-solving as the most preferred objective and 35% thought of a career as the least preferred objective. Around 41% of the teachers considered sustainable practices and chemical concepts as the most preferred goal whereas 19% of students thought these two as the most preferred goal.

This study helped to infer that to align the goals of teachers, students, and the CER literature, the experiments could be planned in a way that during the process of problem-solving the chemical concepts could be learned and the problem itself could be designed to offer inquiry experience. With these objectives in mind, an inquiry module on the estimation of vitamin C was developed to understand the feasibility of implementing inquiry modules in the colleges.

2.4 Introduction of inquiry in the undergraduate lab: A pilot study

Estimation of vitamin C is an experiment that is a part of the present Mumbai University syllabus. This experiment presented in a conventional style was converted to an inquiry module wherein the task involved the analysis of multiple samples available in the market (such the vitamin C supplements) by multiple titrimetric methods. There were three components to this task; pre-lab, lab, and post-lab components. The objectives of the study were to understand, a) the feasibility of implementation of an inquiry-based experimental module in an undergraduate chemistry laboratory and b) the student's perception of the inquiry module.

The study indicated that the students faced difficulties with molar calculations and also found the lab task puzzling. However, through class discussion, they understood that they need to be mindful of the components of the sample which can impact their readings. The post-lab discussion helped them to come up with the reasons for the deviations from the results. All students completed the task.

Students' perception questionnaires indicated that they found the task interesting and challenging even though many found the calculations daunting. Two main highlights stated by students were a) the freedom to explore/experiment unlike the rigid lab systems in their college, and b) the familiar context as an interesting aspect.

This result suggests the feasibility of, a) converting the existing lab experiment to an inquiry-based module, and b) introducing inquiry in authentic settings of state colleges in the Indian context, even with limited resources. However, the study also indicated that an introduction of a moderate amount of inquiry adds to the difficulty level, and thus, students need appropriate scaffolding to help them with lab tasks based on the inquiry approach.

All these inputs helped me to conceptualize my work in developing an inquiry approach for lab experiments, and to introduce Problem-based learning (PBL) as a higher level of inquiry with the help of scaffolds. The next chapter presents the conceptual and theoretical framework for the same.

Chapter 3. Problem-based Instruction: Conceptual and theoretical framework

3.1 Conceptual framework

3.1.1 Inquiry Instruction

Inquiry instruction is a student-centric approach where students take charge of their learning. The teachers act as content experts and facilitators in such settings. In this constructivist environment, the learner builds on prior knowledge, reflects and presents his/her knowledge, thinks critically while working in small teams. Inquiry-based instruction begins with a question/hypothesis to be investigated, follows closely the steps of scientific methods to arrive at theory/understanding. In terms of inquiry-based learning and PBL, the difference based on whether the investigation is driven by a question or a problem. While IBL is described by the levels of inquiry, PBL is recognized by the nature of the problem whether ill-structured, ill-defined, unsolved, or puzzling. The following section describes PBL in more detail.

3.1.2 PBL Instruction

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. They collaboratively reflect on what they have learned and engage in argumentation and reasoning on the developed strategies for problem-solving. The ill-structured problem provides the requisite challenge to fill the knowledge gap facilitating knowledge construction. This student-centric approach develops critical thinking skills and motivates students to find a solution depending on their ideas, not essentially requiring them to arrive at a predetermined result.

3.1.3 Role of the problem

The literature suggests the problem should be ill-structured and complex enough to support the intrinsic motivation of students at the same time it should not be frustrating. The problem should provide scope for argumentation and reasoning. The problem could be classified based on the nature of the task involving the development of the concept, skill, and application of the concept. It could be presented as a description of an event, or as a set of questions. In any case, the starting point should be focused on the capabilities/skills that the students are supposed to learn to equip themselves for working with complex real-life problems.

3.1.4 Role of Facilitator in PBL

The role of the teacher/instructor changes to that of a facilitator who provides guiding questions, moot discussion, monitor team dynamics, ensure collaboration and prevent digression while in discussions. 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.

3.1.5 Role of Students in PBL

The students in PBL need to take up ownership of their learning through decision-making, collaborative problem-solving, shared knowledge construction, and self-directed learning. 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.

3.2 PBL and Learning Theories

3.2.1 PBL learning is an integrated approach to learning, drawing on several learning theories and paradigms: Constructivism, Humanistic theory, Experiential Learning, etc. (Savin-Baden & Major 2004; Kemp, 2011). Many models have been proposed to explain the learning process in PBL.

The constructivist theory and humanist theory suggest that new knowledge is built upon pre-existing understanding. Likewise, the information processing theory suggests the processing of new information is dependent on the connection that the new information can form with the existing information in the long-term memory. All of these theories highlight the need for prior knowledge that forms the foundation for learning. PBL emphasizes the need for pre-requisite knowledge. The significance of environmental factors leading to effective learning is highlighted by the social constructivist (Vygotsky) and Kolb's theory.

As per Kolb's theory (Kolb, 1984), there are four stages that a learner must undergo for meaningful learning. The first stage is related to the concrete experience (CE), followed by reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE). During the CE stage, students engage with a concept in an active learning mode. To reflect on the experience/learning from the CE stage, students receive and give feedback during the RO stage. AC stage helps students to generate models of what is experienced. Finally, The learnings from the previous three stages are put into practice during the AE stage (Konak et al., 2014).

In the context of the PBL chemistry laboratory, we think 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 (Varadarajan & Ladage, 2022a). In my study, I have considered Kolb's cycle as the guiding theory to sequence the scaffolds.

3.3 Learning Models on PBL

Several learning models have been proposed to understand how learning can be affected by the PBL approach. For example, Overton, (2016) proposed a four-stage cyclic learning model comprising of understanding the problem, identifying what is needed to know, learning what is required, and finally applying the learning to solve the problem. Flynn & Biggs, (2012) proposed a six-step problem-solving cyclic strategy involving engaging with the problem and getting motivated to take up the task and understand and define the problem, followed by an exploration of the ideas to plan and execute the ideas and in the final step to reflect on the process. Hmelo-Silver (2004) too proposed a six-step cyclic model. The additional steps proposed here are related to generating a hypothesis and the acquired knowledge is applied to evaluate the hypothesis leading to a possible solution to the problem.

The instructional design of the module developed for my study draws from these learning models more specifically is based on the model proposed by Hmelo Silver, 2004. The instructional design involves components for understanding the problem, acquiring the relevant knowledge for problem-solving followed by executing the idea, and finally reflecting on the entire process.

Since PBL is backed by strong theory and robust models suggested by educationists and researchers, this instructional style is adopted in many domains of higher education including the undergraduate chemistry laboratory. Researchers such as (Mc Donnell et al., 2007; Nagarajan & Overton, 2019; Ram, 1999) have implemented PBL instructional style in the undergraduate chemistry laboratory.

3.4 Factors leading to ineffective implementation of PBL

Boud & Feletti (2013) list the reasons that can lead to ineffective implementation and they can be, a)Ineffective teaching strategies not in line with the prescriptive of PBL, b) the lack of requisite stimulation for deeper, holistic thought, c) the assumption that the problem involves trivial problem-solving, d) inadequate motivational level of students for self-directed learning, e) acquisition of misconceptions or inability to organize the knowledge gathered through various resources by the students and, f) high cognitive load that the students leading to inability in processing the new knowledge. Thus, for successful implementation of the PBL approach, it is important to use appropriate scaffolding.

3.5 Scaffolding for Success in PBL

Scaffolds are tools that support learning. Scaffolds help students to articulate and reflect while completing a PBL task (Hmelo-Silver et al., 2007). 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. Agustian & Seery, (2017) state that an undergraduate chemistry laboratory is a complex learning environment because the laboratory has all the three components that define a complex learning environment i.e., the integration of knowledge, skills, and attitude, b) coordination of skills that are qualitatively different, and c) transfer of learning to a real setting. Thus, an appropriate scaffolding strategy needs to be adopted. One of the ways to help students accomplish success in cognitively complex tasks such as PBL is by adopting effectively scaffolded pedagogy. A scaffolded approach is a promising way to mitigate the difficulty level that an inquiry task presents.

Chapter 4. Development of Indigo Lab Course

4.1 Design Principles

Based on the literature review and the pilot study, I developed a module on Indigo dye with the purpose of, a) introducing inquiry incrementally from lower to higher levels, b) providing a holistic view of indigo dye through the System Thinking Approach, c) integrate different domains of chemistry such as organic, physical, analytical and environmental chemistry, d) develop Science practice skill and e) provide scaffolds for the PBL environment

Indigo dye was chosen as the theme for the development of inquiry modules with much deliberation since it provided an interesting motivating context (used in students' fashion clothing) in addition to the historical, cultural, and environmental perspectives.

4.2 Instructional Principles

The indigo short course consisted of four experiments starting from the synthesis of indigo dye to the dyeing of yarns, analysis of the generated wastewater, and treatment of this wastewater. The procedures for the first two experiments were provided to keep the tasks at lower levels of inquiry involving formulating hypotheses and data collection. For the remaining two tasks, the students needed to design their experiments which involved higher levels of inquiry (Table 4.1).

Table 4.1 Incremental level of Inquiry

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

Ref.(Varadarajan & Ladage, 2022b)

The learning objectives related to chemical content, science practice skills, and laboratory skills were identified in all of these experiments to ensure a holistic laboratory learning experience.

4.3 Design of Scaffolds

Based on the pilot study and the literature, various kinds of scaffolds were planned to introduce higher levels of the inquiries, as part of PBL-based experimental modules. The scaffolds designed were –a) a simple precursor task to understand the components of an Experimental design (ED), b) reading material for developing the prerequisite knowledge needed to complete the task, c) group discussion among the small teams for reflective and collaborative knowledge construction and e) navigating pointers in the lab task sheet for prelab, lab and post lab report writing. These scaffolds were sequenced as per Kolb's stages for meaningful learning among the PBL-based experimental tasks (Table 4.2).

Table 4.2 Mapping Kolb's Cycle with the Scaffolds

Stages of Kolb's Cycle	Scaffolds
Stage 1- Concrete experience	Precursor task, reading material
Stage 2 - Reflective observation	Structured group discussion
Stage 3- Abstract Conceptualization	Navigating pointers in the task-sheet
Stage 4 - Active experimentation	Collaborative problem solving

The precursor task involved planning an experiment to decide on the most suitable vinegar for making pickles from the ones that are available in the market (Varadarajan and Ladage 2021). The reading material was carefully planned to provide an opportunity for decision-making to make a choice based on the cost, the effectiveness of the procedure, green approaches, etc. It contained the prerequisite information for planning the task. The group discussion was structured to provide opportunities for different teams to present their plans. The simplest plans were presented first followed by the more advanced plans. The questions raised during the group discussion were expected to refine and modify the initial plans.

All four experiments had a prelab, lab, and post-lab component. To report the investigation there were two kinds of prompts given to students. The first one was Science Writing Heuristics (SWH) mentioned in the literature for reporting an inquiry experiment and the second one was Lab Report Pointers (LRP) developed to integrate the pointers from the conventional lab and the inquiry lab. The need to change the pointers were considered necessary after the reports from the first three trials indicated that these pointers could not elicit elaborate report as expected).

Chapter 5. Research Methodology

5.1 Research Questions

As discussed before, the research work consists of two studies. The research questions for study one aimed to understand the role of the scaffold in PBL-based tasks and the research questions in this study were,

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

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

Study 2 explored the implementation of the short course on indigo dye with a thrust on science practice skills. The research questions were,

RQ-3: What does undergraduate students' chemistry lab report indicate about the science practice skills (hypothesis, data interpretation, discussion) acquired through incremental inquiry levels?

RQ-4: What is the student's perception of working in teams in the given PBL task?

A quasi-experimental qualitative approach was adopted for exploring research questions 1 and 2 as part of study 1. And for study 2, a case study approach was adopted to explore research questions 3 and 4.

5.2 Study 1: Role of Scaffolds in Devising an Experimental Design

5.2.1 Methods

The study aimed at understanding the role of scaffolds in devising the ED. Experimental design (ED) is a key inquiry skill in an undergraduate laboratory and often students struggle here (Shi et. al, 2011). In addition, ED has a precedence to the lab task. Even to begin the lab work, ED is required. Especially in an inquiry task such as PBL, it is expected that the students devise their EDs for solving the given problem.

5.2.2 Participants

There were 75 students in all who participated in this study and worked in small teams, with 3 students in each team. Informed written consent was obtained from the students after briefly describing the research project.

In the institute setting, there were two kinds of teams, those who were given scaffolds to design the EDs (a scaffolded group, SG) and the other group that did not receive any scaffolds to design the ED (an un-scaffolded group, USG). The SG received all three scaffolds for planning their ED whereas the USG had only access to the internet for the ED. The ED by students as an expected outcome after intervention (that is presence and absence of scaffolds) met the criteria of the quasi-experimental research design as represented below in Table 5.1.

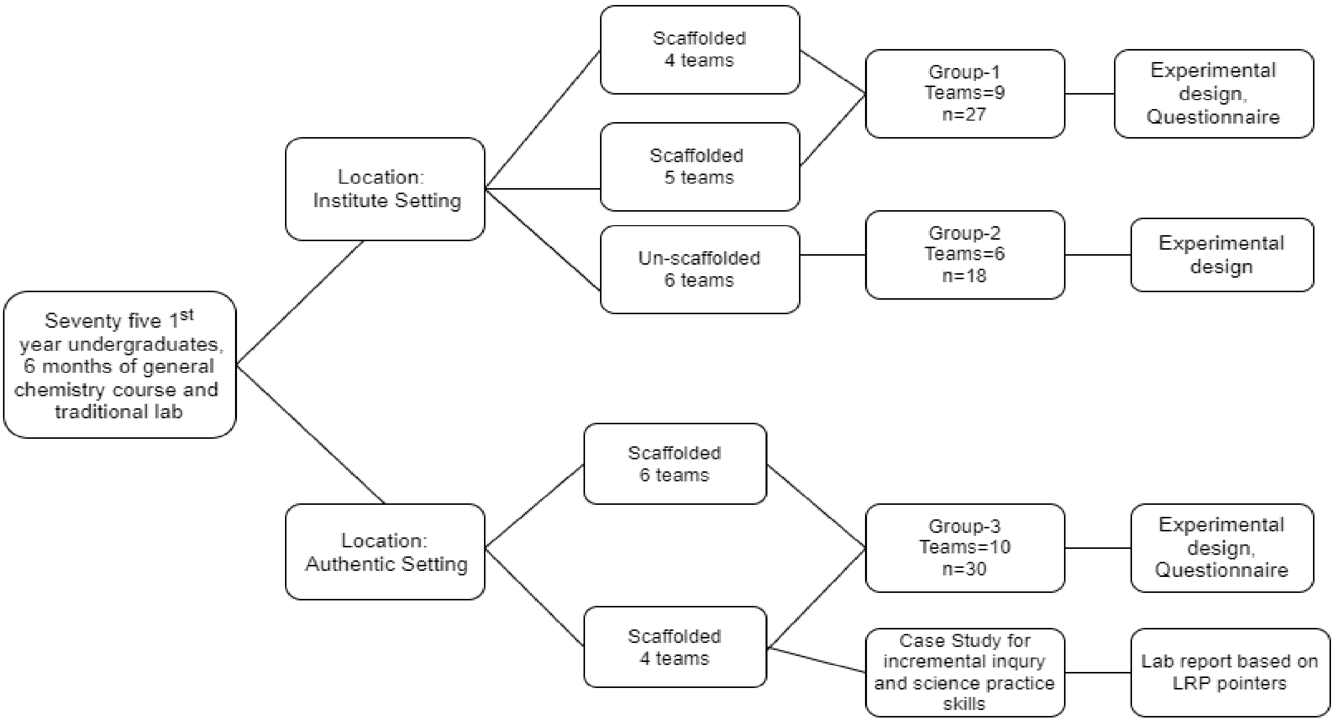
Table 5.1 Design of the quasi-experimental study

Groups	Intervention	Outcome
Experimental group (Scaffolded group)	Scaffolds	Experimental design
Control group (Un-scaffolded group)	No scaffolds	Experimental design

5.2.3 The Research Design

The research design of study 1 is represented in Figure 5.1. The study was conducted in two locations (Institute and Authentic setting) and there were two groups, scaffolded (SG) and un-scaffolded (USG). The total number of workshops conducted was four. There were four and five scaffolded teams in the Institute setting and six teams in the Authentic setting. 6 teams volunteered to be a part of the un-scaffolded group in the Institute setting and none in the Authentic setting. The data from two workshops in each location for the scaffolded teams were combined after validating the equivalence of the groups. The data collected consisted of experimental design by the teams and responses by the individual students to the survey questionnaire. Two external observers have given their reports about the implementation of the module in the laboratory at the institute setting. One of the external observers followed one team (chosen randomly) for tracking their interactions during pre-lab, lab, and post-lab work. The participation in un-scaffolded (USG) group was voluntary.

Figure 5.1 Research Design, Study-1



5.3 Study 2: Case Study on the Implementation of a short course with Incremental Inquiry levels

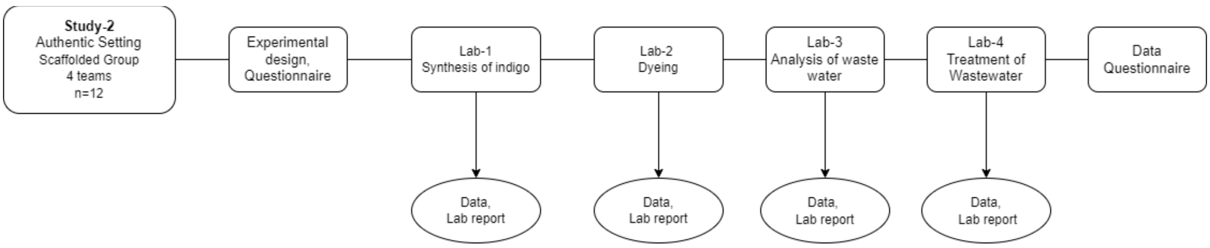
5.3.1.Methods

The study explored the impact of incremental inquiry on science practice skills. To answer research questions 3 and 4, a longer engagement with the data collection was needed with four different experiments. The course was conducted for almost four months and with three components of the lab namely, prelab, lab, and post-lab work was conducted. This study was carried out in the authentic setting of a college with 12 first-year undergraduates forming 4 teams.

5.3.2.Research Design

All the participants were provided the scaffolds and after each lab work their lab reports based on the LRP pointers were collected as the data. In addition, the experimental design and the survey questionnaire formed the data for this study. The design is presented in Figure 5.2.

Figure 5.2 Research Design, Study-2



5.3.3 Data Analysis

To assess the laboratory report, a rubric was created and validated by experts. Scores were given for the testable hypothesis, procedural/ED, data, and discussion.

5.4 Validity and reliability aspects of the Research

The following validity and reliability aspects were followed for both studies 1 and 2.

The Kruskal Wallis test was conducted for the 12th-grade board exam scores used as criteria for entry into undergraduate colleges. It helped us to check the equivalence of the participants in different groups. The analysis showed there was no significant difference in the prior academic achievement score of students who participated in two workshops conducted in the Institute setting and, thus, the ED data from the two workshops were combined. Similarly, since there was no significant difference in the prior academic achievement score of students who participated in two workshops in the Authentic setting, the EDs data for both workshops were combined. The data from the Institute setting and Authentic setting were analyzed separately. Additionally, the following aspects were considered for the validity and reliability exercise.

a) Experts with adequate experience in teaching undergraduate students were invited for validation of the content of the precursor task, reading material, and rubrics.
b) External coders for the qualitative analysis of group discussion with 83% negotiated agreement for the reliability of the coding.
c) Cronbach alpha for the inter-evaluator consistency of the ED of the precursor task (0.83) and indigo task (0.93).
d) Students' perception data were analyzed to corroborate the findings from both studies.
e) Field observation notes by two external observers.

5.5 Instruments for evaluation of ED

The rubric developed for the evaluation of the experimental design (ED) by students for the indigo PBL task is discussed below in Table 5.2. The rubric was validated by experts.

Table 5.2 Rubric for evaluation of Experimental Design

Descriptor	0 point	1 point	1 point	1 point	1 point
Parameters were chosen for analysis	None	pH	COD	Suspended Solids	color
Treatment chosen	None	for pH	for COD	for Suspended Solid	for color
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/sawdust/ 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

Ref.(Varadarajan & Ladage, 2022a)

To understand students' perceptions of the indigo module and the scaffolds, a questionnaire was developed (given in Annexure I). It consisted of questions based on the Likert scale, rank order, and open-ended questions. The questionnaire also explored the difficulty level of the reading material and problem-solving and the experience of teamwork.

Thus, the data collected included experimental design, lab-task sheet for precursor and indigo task, annotated reading material, transcripts for group discussion, and student perception questionnaire. Lab reports and questionnaires for the case study exploring the science practice through incremental inquiry levels were the data for the second study. The analysis of data and the results of these two studies are presented below.

Chapter 6. Analysis of data from Study 1

For the first study, the data were qualitatively analyzed to understand the impact of scaffolds on the quality of the ED in the Institute setting and the Authentic setting.

In the second study, the focus of the qualitative analysis was on understanding how the students progressed in the hypothesis formulation, experimental design, and the discussion of their results as the components of science practice skills.

6.1. Study-1, Results from a quasi-experimental study on scaffolds

This section describes the results of the analysis of the EDs of the following groups/settings

- EDs of scaffolded (SG) and un-scaffolded (USG) groups in the Institute setting
- EDs after giving two scaffolds and after giving the third scaffold in the Institute setting
- EDs in Institute and Authentic settings
- Students' perception of the scaffolds in the Institute and Authentic setting
- The analysis of individual scaffolds (precursor task, reading material, and group discussion) in the Authentic setting
- Analysis of the external observers' report of the lab work

6.1.1 Scaffolded (SG) and un-scaffolded (USG) groups in the Institute setting

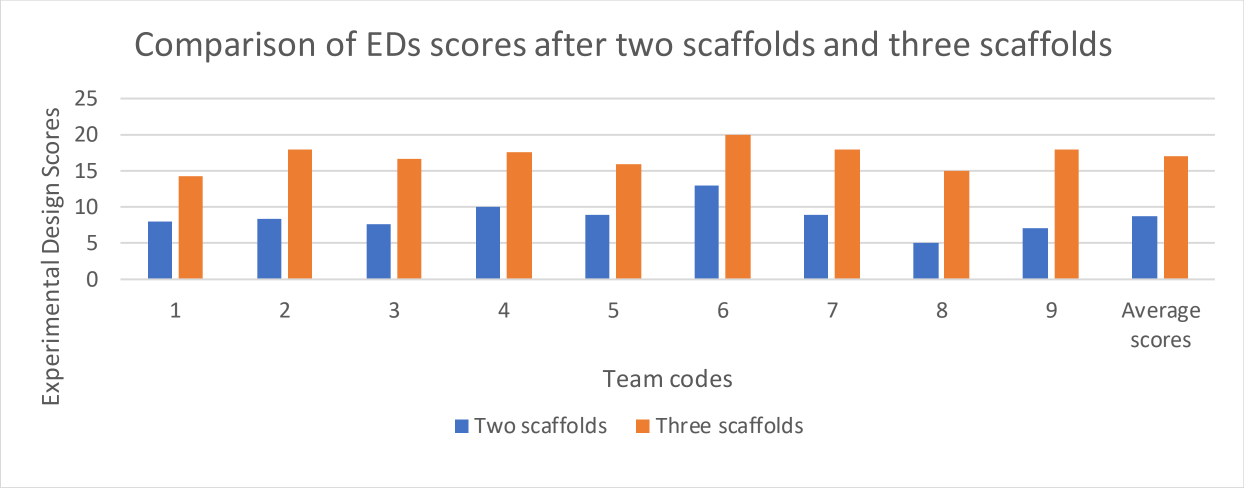
The comparison of the ED scores of the SG and USGS in the institute setting indicates improvement of the mean scores after giving the scaffolds. The mean score was found to be 6 and 17 for the USG and SGs out of a maximum score of 28. Further, the EDs of the USG and SGs differed in terms of providing a feasible design concerning the availability of time, chemicals, and equipment in undergraduate labs. The other difference was in the sequencing of the steps of the task.

The EDs by the USG indicate that providing only the problem statement is closer to open inquiry requiring more time for a concrete understanding of devising an ED. Further, the difficulties mentioned by students of the USG in a written response to a question in the questionnaire are –a) difficulty in understanding the online information, b) insufficient accessible information to plan c) time-consuming d) difficulty in accessing the restricted articles. The teams in the scaffolded group could sequence the task to analyze the wastewater prior to and post to the chosen treatment in addition to providing a feasible method for wastewater treatment.

6.1.2 Two Scaffolds vs 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. There was an obvious difference in the EDs after the third scaffold (Figure 6.1).

Figure 6.1 ED scores with two and three scaffolds

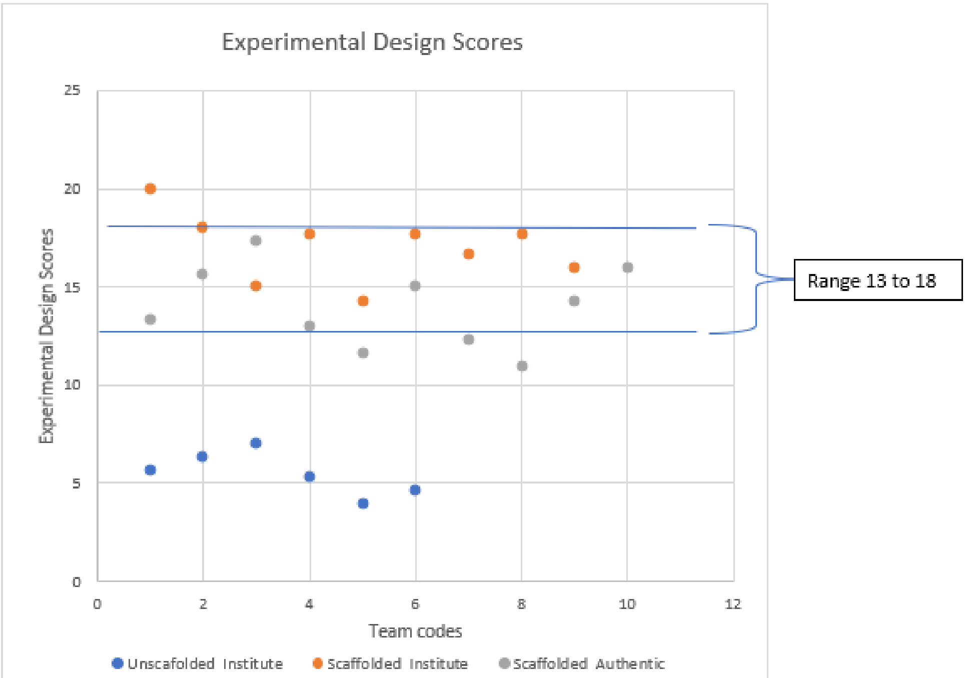


6.1.3 Institute and Authentic settings

To understand the transferability, the ED was compared between the Institute and the Authentic setting. It was found that the number of teams that included the components such as the parameters of analysis, logical sequencing, and the feasibility of treatment in their EDs was almost identical in the two settings. All the teams gave a feasible plan in both settings whereas *optimization* was missed by some teams in both settings.

Most of the teams had ED scores in the range of 13-18 in both settings (Institute and Authentic) as indicated in Figure 6.2. The mean scores of the Institute and Authentic settings were found to be 17 and 14, respectively. However, no team scored a full 28 because no team included the tools of measurement in their EDs.

Figure 6.2 Experimental Design Scores

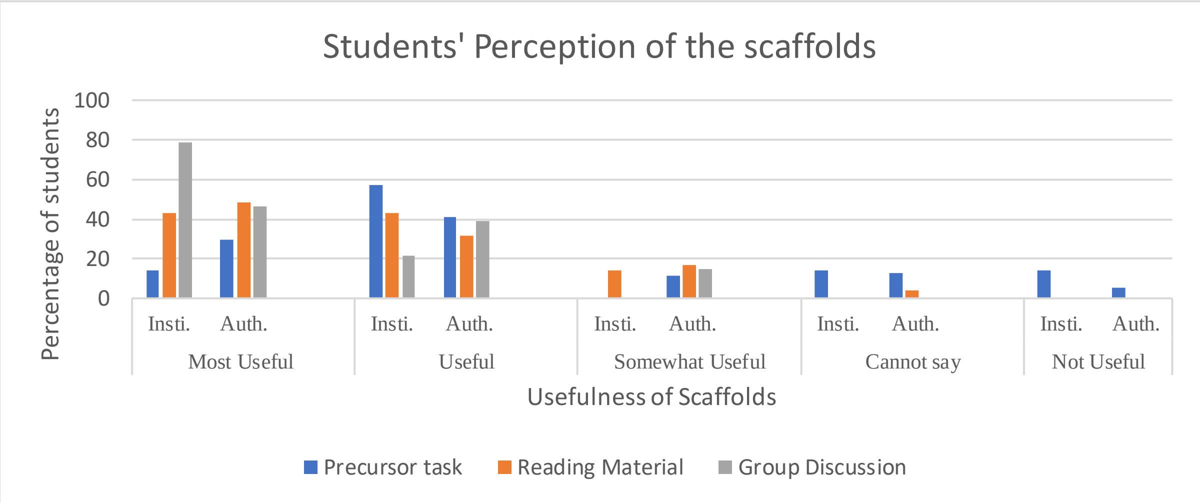


Thus, I infer that the qualitative and quantitative trends in the ED of the scaffolded PBL are similar in both settings. I had anticipated a larger difference due to the significantly different prior academic achievement scores. It is surprising but encouraging that the participants in the Authentic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

6.1.4 Students' Perception of scaffolds

Students in both settings found the group discussion as the most important scaffold while some were not sure about how the precursor task helped them.

Figure 6.3 Students' Perception of the Usefulness of the Scaffolds



Insti* Institute, Auth.* Authentic

6.2 Analysis of individual Scaffolds in the Authentic setting

6.2.1 Precursor task

In the authentic setting, the effect of scaffolds was more closely explored. It was observed that 7 out of 10 teams scored either a full six or five in the ED of the precursor task. The content and the task were deliberately kept easy to draw attention to the design aspect resulting in a high score. Students gained concrete experience in designing an experiment with familiar content.

6.2.2 The reading material

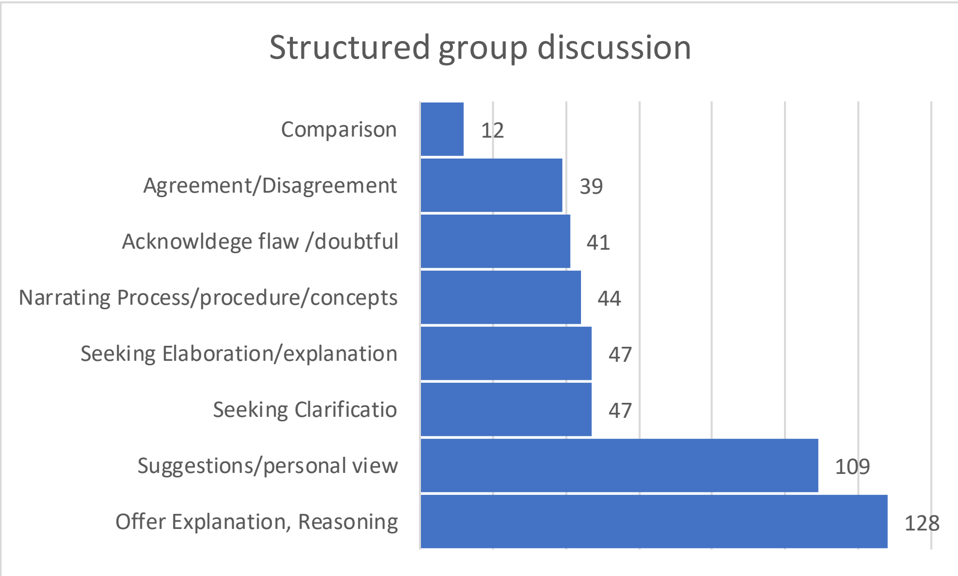
The students had to understand the contents of the reading material and select the information relevant for planning their task. Teams who supplied their highlighted reading material (6 out of 10) could identify relevant concepts, but not all could select the expected number of parameters or treatments. To understand students' viewpoints about the content of the reading material, I gave a 3-point Likert scale questionnaire (easy, moderately difficult, and challenging). The analysis of questionnaire data of 30 students indicated that 56% of them found the content of 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 (60%) found it moderately difficult and 23% found it challenging. This suggests, though many students found the contents of the reading material easy to comprehend, synthesis of the content to develop an ED for the given task was difficult for the students.

6.2.3 Group Discussion

Students presented their ED and that mooted both clarificatory questions as well as demanded explanations.

Codes were created deductively and applied to the audio transcript and the frequency of the codes was calculated and is presented in figure 6.4.

Figure 6.4 Frequency of the aspects of 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 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. Student's quotes indicate that the structured group discussion may have provided an opportunity for reflective thinking which led students to a better understanding of their choice of wastewater treatment processes.

6.3 External Observer's Remarks

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 just devising a plan and were discussing the reasons why sawdust would work trying to hypothesize. However, they did not resort to available resources (reading material or the internet) to gather more information on the same, noted the observer. The observer pointed out that the lab work offered challenges which included,

"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 observer noted that there was a shift in the attitude on the subsequent day after students confronted the challenges on day 1. They became more comfortable/familiar with the lab and the lab work and tried working with many variables and noted,

"… 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".

The second observer noted that,

"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 group(team) *on track in terms of their plans but at no stage was 'hand-holding' done. 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.*

Pointing out at the time given to students for completing the task, the second observer felt that better time management is required because in both the prelab and lab, work got extended beyond the prescribed time. This observer also recorded that the interpretation of results could have been deeper from the large quantum of data collected by students.

The observer's notes help me to infer that the intent of the module, namely to learn to design an experiment and develop science practice skills was achieved through the indigo lab.

Chapter 7. Analysis of data from Study 2

7.1 Results from Case Study on Science Practice Skills

This study was conducted over a period of every week four months covering the prelab, lab, and post-lab components for four experiments with incremental levels of inquiry. Students' team lab reports based on the LRP pointers were collected as data and were analyzed qualitatively. The pointers included the Aim of the experiment, Chemicals, Theory, Hypothesis, Procedure, Data (qualitative and quantitative) Results, and Discussion. There were 16 lab reports from four teams and four experiments.

7.1.1 Hypothesis

The level of the inquiry remained the same for experiments 1 to 2 though the complexity of the task enhanced. Yet the students identified the factors affecting the experiment on the synthesis as well as the dying process and formulated the hypothesis accordingly. The hypothesis by group 3 is given as an example in Table 7.1.

Table 7.1 Improvement in the quality of hypothesis between experiment-1 and-2

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
Exp.-2 (Dyeing)	*"Elevated/depressed temperature can affect indigo dyed yarn's physical appearance, particularly color. With an increase in temperature, the color 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

The hypotheses by various teams were tracked for all four experiments to understand the change (improvement) in the quality of the hypothesis. The data on hypotheses indicated that there was an improvement in the quality of the hypothesis even when the complexity of the task increased from the first experiment to the second across all the teams.

The results for group 2 as an exemplar are given in Table 7.2 to understand the trend.

Table 7.2 Exemplary hypotheses by Team 2

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 synthesis 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 team could think not only about the possibility of an alternate hypothesis but provide 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 teams from the level they were initially at.

7.1.2 Experimental Design

In the designing of the ED, students utilized the reading material and there were indications of them exploring the internet for obtaining more information. They engaged in the reflection as was indicated through the group discussion and the transcripts of the group discussion. The teams implemented the plans in the laboratory and collected data however, for labs 3 and 4, although the student teams had planned for the analysis of three parameters, except one, the other three teams could analyze only two parameters i.e., pH and COD.

7.1.3 Discussion

Students completed the LRP report of the lab work presenting the results and discussion (Table-7.3).

Table 7.3 Discussion of the results by various teams

Groups	Exp.-4, Results and Discussion
Grp-1	*"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 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."*
Grp-3	*"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 pH of treated waste found to be neutral after the treatment with activated charcoal. 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 found to be lower than untreated wastewater."*

One could infer from Table 7.3 that all the teams have formulated the results and discussion section as per the pointers in the rubric. Explanations offered by teams for experiment 4 (highlighted part) are interesting. For example, Grp 1 has thought of two plausible explanations for their observation of experiment 4. Grp2 understands that their results contrast with what the literature says, thus, they should explore further before making a conclusive statement. Grp 3 offered a biological explanation of the observed chemical phenomenon exhibiting an interdisciplinary perspective. Grp-4 has mentioned only the results and needs a little bit more training/ exposure in formulating hypotheses as well as the result and discussion section. Such varied performance is expected in an academically diverse classroom.

7.1.4 Lab reports

The scores of the lab report indicated that 13 out of 16 reports had a full score of 3 points for the discussion section (Table 7.4). From this, we could infer that the students could connect the hypothesis to the results obtained by them in the investigation and could offer an explanation for their observed result. Since all the teams could score 12-15 for the lab report (max. score 15) we could infer that the students included most of the aspects in the report that the rubric assessed.

Table 7.4 The scores obtained by each team on the four different lab tasks

	Syn.	dyeing	analysis	treatment
	Exp.-1	Exp.-2	Exp.-3	Exp.-4
Team-1	15	14	12	15
Team-2	15	14	15	12
Team-3	15	15	9	13
Team-4	11	15	12	14

Responses in the perception questionnaire indicated that the students did not follow the experiment in the recipe style. They acknowledged that there was a close to the research-like experience. Their responses also indicated that the design principles related to developing science practice skills and integrative perspective were met during the implementation of the module.

Students highlighted the strength as well as the issues they faced while working in teams suggesting a need for a more detailed study to understand the dynamics existing within the team learning.

Chapter 8. Conclusion

8.1 Summary of the study

The study explored two sets of research questions, the first one was related to the role of scaffolds in helping students develop the experimental design in an undergraduate chemistry lab. This research question was explored by a quasi-experimental qualitative design. Lab reports, experimental design, audio transcripts, and perception questionnaires were the data for the study.

The second set of questions explored the impact of the incremental levels of inquiry on science practice skills which was answered through a case study design.

8.1.1 The results from the Quasi-Experimental Study on the role of scaffolds

As per Kolb's Experiential Learning Cycle (ELC), students undergo four stages for meaningful learning. This study explored the first three stages using a scaffolded approach for the planning of the experimental design in PBL. The scaffolds were designed to contribute to different aspects of the ELC, for example, the precursor task, reading material, and group discussion helped with the first three stages respectively. Our study suggests that the scaffolds provide a way for students to move through the first three stages in the ELC for effective planning of the given PBL task. The scaffolds appear to be useful and to have helped students plan the ED which is an important antecedent to the PBL laboratory investigation.

8.1.2 The results from the Case Study on the impact of incremental levels of inquiry

A short course centered around indigo was carried out as a series of four experiments and was successfully implemented in the authentic settings of students' college. All the experiments were completed successfully. Pre-lab work, group discussion, lab work, and LRP pointers helped students to engage in science practice skills. The tasks were incremental in complexity and inquiry level, and students' science skills such as understanding variables, formulating hypotheses, and linking results to the hypothesis improved with the inquiry level through this short course. Students felt that they got a research-like experience, though some students mentioned that the teamwork has both merits and limitations. The incremental inquiry style appears to be a promising approach to introduce inquiry in state colleges even if there are limited resources.

8.2 Limitations

The case study on implementing the short course was studied in one setting. More such trials were planned but Covid -19 pandemic hindered this. Efforts were made to interview students through online mode but due to poor internet connection, the quality of the recording was not good. The class size of 4 to 6 teams (n= 12 to 16) was chosen to comply with the desired student-teacher ratio (1:15) for a typical lab instruction and the influence of the class size on group discussion was not assessed. Additionally, I could not compare the un-scaffolded and scaffolded groups in the authentic setting due to the unavailability of volunteers for the same.

8.3 Future Directions:

Some important aspects that could be explored in the future are, a) to study the effect of scaffolds on the AE stage of Kolb's cycle, b) explore Systems Thinking imparted to students, and c) execution of the module by multiple facilitators to understand the needs to orient teachers as a facilitator.

8.4 Implications of the study

8.4.1 For researchers

By using Kolb's Theory, I was able to investigate students' engagement with the first three stages of this theory. I also investigated how a combination of scaffolds sequenced according to the stages of Kolb's ELC facilitated students to accomplish the given task in a complex learning environment such as the PBL laboratory.

8.4.2 For Curriculum designers

The development of the pilot study, precursor task, and indigo task indicate that an experiment with a simple procedure can be modified into an inquiry module. The study also suggests a way to connect lab experiments from multiple domains in a coherent manner in the form of a short course while retaining the learning objectives of individual labs. The incremental approach for introducing inquiry can be considered by curriculum designers, as adequate engagement with the inquiry tasks is needed to internalize the science practice skills. The study suggests that PBL-based tasks can be used for chemistry laboratory curriculum development in the Indian context and should consider the use of a combination of scaffolds with an emphasis on structured group discussion.

8.4.3 For practitioners

In the Indian context, the current work presents a way forward in introducing inquiry in regular colleges with conventional lab practices. The study suggests that even with resource and infrastructural constraints, shifting to inquiry labs is feasible. However, the teachers have to assume the role of facilitators. The labs, such as the indigo dye, focus on learning science practice skills and self-directed learning of the content; it completely refutes the overemphasis on the correctness of the result of the lab work, thereby minimizing the frustration that can be set in by procedural errors as it happens in a conventional lab.

Note: A large part of Chapter six (Analysis and Results) is adopted from my published work. Some content of Chapter eight on the conclusion is adopted from my published work which is referenced below.

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Appendix I

Questionnaire

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

Q2.The following methods/materials were used for supporting the PBL task.

Put a tick mark on the column which you may find as the most appropriate.

Description	Most useful	Somewhat useful	Useful	Not useful	Cannt say
Precursor					
Reading material					
Group Discussion					
Labtasksheet					
Pointers for writing the report					
Facilitators guidance					

Q3.Give ranking from 1-6 depending on the usefulness of these descriptors in completion of the task.

Rank 1 means most useful and rank 6 means less useful as compared to the other descriptors.

Descriptor	Rank 1st to 5th	Reason for the choice of first rank over the others
Precurssor		
Reading material		
Group Discussion		
Labtasksheet		
Pointers for writing the report		
Facilitators guidance		

Q4. Write your experiences about the interaction/discussion that you have had.

Q5. In the following section some description is given related to the way the module was executed by you. You are required to put a tick mark on the descriptors that indicates your viewpoint/perception about the module and its execution.
Put a tick mark whichever box is applicable.

Reading Material and planning

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 a new information	To a lesser extent	To some extent	substantially

Problem Solving

The following table indicates your opinion about the way 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	challenigng
Planning of the task	Easy	Moderately difficult	Challenging
Use of selected information from literature	Not effective	Moderately effective	Effective
Execution of the task was	Easy	Moderately difficult	Challenging
Arriving at the solution to the problem was	Easy	Moderately difficult	Challenging

Group work

The following table indicates your opinion about the work done by you and your group members as a group.

Interaction amongst 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