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Engaging chemistry teachers with inquiry/ investigatory based experimental modules for undergraduate chemistry laboratory education

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Abstract: The experimental domain is central to chemistry education at undergraduate level. It is important that teachers teaching chemistry at this level are oriented with research informed approaches based on work done in chemistry education research. Currently, academic autonomy is being granted to various state colleges affiliated to university system in India and such an orientation is the need of the time. The chemistry group at HBCSE has been conducting capacity building workshops in the experimental domain for chemistry teachers as part of the National Initiative on Undergraduate Science (chemistry) programme. The primary aims are a) present hands-on experiences of experiments developed using inquiry/investigatory approaches and b) help teachers to reflect on related aspects of pedagogy, assessment and content. Often these experiments are selected from the existing lab manuals for teachers to witness how to adapt and modify experiments from their own lab manuals. This paper discusses examples, structure of workshops and feedback from participating teachers who are receptive to these alternative approaches. Conduct of such workshops in regular college set-ups can help teachers to reflect on the existing teaching-learning practices in conventional laboratories. In our opinion, the entire process is equally important to those individuals involved with similar activities globally.

Keywords: ICCE 2024; inquiry based teaching; teacher professional development; curriculum development; inquiry based learning; laboratory work

1 Introduction

The chemistry laboratory education is an important integral component of chemistry courses at undergraduate (UG) level globally. The work done in Chemistry Education Research (CER) over several decades has critically looked at chemistry lab education at the UG level. There is significant discussion in CER literature about the goals, aims and learning outcomes of chemistry laboratory education. Kirschner and Meester (1988) suggested student centred objectives for chemistry laboratory work should include making hypothesis and designing experiments which involve higher order skills. Carnduff and Reid (2003) suggest three broad areas, namely, practical skills, transferable skills and intellectual stimulations as the primary reasons for why the chemistry laboratory work is needed. While further elaborating a set of reasons for inclusion of laboratory work in chemistry curriculum, they also highlight that these reasons are in contradiction with the existing practices in a general chemistry lab. According to Agustian and Seery (2017), chemistry laboratory education is a distinct component of education, with the intention to teach students about how to "do science". Seery (2020) describes chemistry laboratory as a

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complex learning environment as it demands integration of knowledge, skills, and attitude. He states affective domain factors such as motivation, emotions, and expectations are also important for chemistry labs (Bretz, 2019; Seery, 2020; Seery et al., 2024), and many other researchers have given broad insight into the designing, teaching/conducting, and assessing chemistry laboratory curricula at colleges and highlight that there is a need for reconsideration of the approaches about how we should incorporate laboratory work into a chemistry curriculum.

In context of chemistry lab education, one of the primary concerns that has been raised in CER literature is what kind of learning is happening in the lab. In the conventional (also termed as traditional/expository) approach, the curriculum designer defines the set of experimental tasks to be performed as part of lab courses. Often, students perform the tasks following teacher's instructions and as prescribed in the lab manual. The outcomes are predetermined and thus, the tasks are performed more in mechanical manner. The results obtained are typically used only for comparison against the expected result which is predominantly assessed (Domin, 1999). He also indicated various benefits offered by the expository/conventional style. He explains that a large group of students can be engaged with the use of minimum resources in stipulated time of 2–3 h. The important role of this instructional style in acquiring basic experimental skills and techniques has also been acknowledged by some other researchers (Bertram et al., 2014; Burnham, 2013).

The expository style is still practiced widely when one has to cater to variation in infrastructure facilities, lab resources, diversity and number of students to be catered in the chemistry lab. However, one cannot rule out the verification mode or cookbook nature of this laboratory style. All these factors are also important in Indian context where state colleges affiliated to a given university spread across several kilometers.

CER literature indicate use of inquiry-based approaches (guided and open inquiry) as alternatives to the conventional mode (Gao et al., 2021; Rodriguez & Towns, 2018; Varadarajan & Ladage, 2022). As given by DeBoer (1991), inquiry-based teaching is inductive in nature, has an undetermined outcome and often requires students to generate their own procedure. This type of activities requires the students to formulate the problem, relate the investigation to previous work, state the purpose of the investigation, predict the result, identify the procedure, and perform the investigation (Tamir, 1977). Buck et al., (2008) nicely elaborates on the existing definitions and confusions about what constitutes inquiry in learning science in general and proposes a rubric to characterize inquiry in undergraduate laboratories. Guidelines and suggestions have been given by many authors and practitioners on how to convert traditional laboratories into an inquiry-based laboratory (Agustian & Seery, 2017; Bruck & Towns, 2009; Domin, 1999; Farrell et al., 1999; Gao et al., 2021; Rodriguez & Towns, 2018; Seery et al., 2024; Thomson & Lamie, 2022). Rodriguez and Towns (2018) makes a comparison of traditional pre/post-lab questions (acid-base titration of vinegar) and a modified version of the same for effective engagement of students in science practices. Inquiry methods do foster student engagement in science practices such as asking questions, planning, analyzing, and interpreting data, etc. (Rodriguez & Towns, 2018). Development of such experimental modules emphasize nature of science as a union of both knowledge and skills which the teacher should be aware of.

In our opinion, it is important that capacity building programmes conducted for chemistry teachers teaching at UG level need to include orientation about the work done related to chemistry lab education, discussion about alternative instructional styles proposed and their merits/demerits. These should also give concrete examples of the experimental tasks developed using some of these approaches and experiences about performing the same in the labs to understand the challenges involved. In this current article, we have tried to explain how we are making efforts to take these discussions to the chemistry teacher community and what are our experiences. We present the structure of the teacher camps, and a few examples of experiments developed and modified with elements of inquiry or pre/post-lab approach. Our camps are primarily conducted for teachers teaching chemistry at UG level in state colleges affiliated to university systems. However, before we discuss these aspects, we will discuss the chemistry lab education in the Indian context.

2 Chemistry laboratory course at UG level – Indian scenario

In India, universities are affiliated to both the central government and state governments; apart from these there are several privately owned universities. More than 100 universities offer courses in chemistry at both the undergraduate and post graduate levels (Krishnan et al., 2016). The state colleges cater to a significant fraction of students at the UG level. The dominant mode of conducting the laboratory sessions is expository style as it is

Table 1: Experimental domains covered as part of UG chemistry lab.

Areas	Academic year[a] and number of experiments			Sub-areas
	First year	Second year	Third year	
Organic chemistry	10	–	–	Organic compound characterization (4 solid), (6 solid/liquid)
	2	–	–	Purification of organic compounds by recrystallization
	–	7	6	Organic synthesis
	–	10	–	Qualitative analysis of bi-functional organic compounds
	–	1	–	Paper chromatography
	–	1	–	Solvent extraction
	–	–	14	Separation of binary mixtures (solid-solid/solid-liquid/liquid-liquid) and identification of one compound
Physical chemistry	3	7	9	Instrumental
	5	4	4	Non-instrumental
Inorganic/Analytical chemistry	5	–	–	Qualitative analysis (two cations and two anions)
	–	1	–	Qualitative estimation (cation), can have multiple combinations
	2	3	–	Quantitative estimation of metals (gravimetry)
	–	7	1	Quantitative estimation of metals (complexometry)
	1	1	1	Quantitative estimation of metals (iodometry)
	–	2	–	Quantitative estimation of metals (redox)
	–	1	–	Purification and estimation (iodometry)
	–	2	2	Complexometric titrations
	–	3	–	Synthesis and estimations (gravimetric)
	–	1	–	Colorimetry
	–	1	–	pH-metry
	4	1	–	Estimation (acid-base titration)
	–	4	8	Complex synthesis
Analytical chemistry	–	–	6	Instrumental
	–	–	6	Non-instrumental

[a]The New Education Policy (2020) is currently getting implemented in India and thus, the UG Bachelor courses are in the process of becoming four years.

economical. The lab education is often teacher centered and makes use of conventional instructional and assessment practices. Table 1 lists areas of the experimental domains covered as part of UG chemistry lab education and the number of experiments in each area[1] as a representative example.

To the best of our knowledge, there are almost no examples of experiments which involved inquiry based/ investigatory or pre/post-lab approach or those involving components of planning and designing of experiments in the Indian UG curriculum. Group work is not yet central to lab education. The lab manuals follow the expository style prescribing the aim, glassware, required list of chemicals, procedure, data tables and inferences.

For teachers teaching at UG level, it is not mandatory to have an education related degree (like bachelor's or master's degree in education) and thus, the exposure to pedagogical dimensions and related innovations is limited. The conventional refresher courses have their thrust on content enrichment especially in theoretical domain rather than experimental domain.

However, in last decade and half, there are significant changes in the higher education segment in Indian context. Post year 2000, the number of colleges/institutions offering UG degree courses have increased exponentially. Implementation of schemes like Pandit Madan Mohan Malaviya National Mission on Teachers and Teaching (PMMMNMTT https://nmtt.gov.in/) has brought in sensitization regarding the pedagogical dimensions in higher education segment and among the chemistry (science) teachers teaching at UG level. International reputed bodies like American Chemical Society (ACS) and Royal Society of Chemistry (RSC) are venturing in STEM education in India. Schemes like Star College programme initiated by Department of Biotechnology (DBT) (https://

1 For colleges affiliated to University of Mumbai.

dbtindia.gov.in/star-college-programme) emphasize "*improving critical thinking and encouraging 'hands on' experimental science at undergraduate level in basic science subjects*". College teachers are expected to engage science students at UG level with hands-on experiences in experimental domain. Additionally, autonomy is being granted to several state colleges and thus, there is scope for redesigning the chemistry (science) curriculum, especially the laboratory component.

The National Education Policy (India), 2020 which is being implemented in India emphasizes on 2 year B.Ed programme for interested students who have already completed their bachelors in a specialized subject or a 4 year integrated B.Ed. programme offered by multidisciplinary Higher Education Institutes (HEIs) offering dual Bachelor's degree in education and a specialized subject (National Education Policy, 2020). With such training, teachers will be equipped to handle both the content and pedagogical aspects in the discipline.

Thus, currently capacity building programme for chemistry teachers teaching at UG level that cater to both content and pedagogical aspects is the need of the time. Since there is less innovation in lab education, it is important to focus our attention on this domain. As the system is becoming more open and receptive, it is important to offer programmes that will orient teachers with research based innovative disciplinary teaching-learning practices in context of chemistry lab education.

3 Workshops/camps for teachers

Workshops for teachers conducted by the chemistry group are part of the National Initiative on Undergraduate Science (NIUS) chemistry programme. NIUS programme is offered in astronomy, biology, physics along with chemistry and is one of the key impact programme of Homi Bhabha Centre for Science Education (HBCSE),[2] Tata Institute of Fundamental Research catering to UG phase of science education within the country.

NIUS chemistry programme conducts activities and workshops both for UG students and the chemistry teachers teaching at the UG level. The growth and evolution of NIUS chemistry programme since its inception in the year 2004 till date is reviewed and is published as comprehensive article (Das Sen & Ladage, 2023). The primary aim of the activities for students is to engage them with enriching experiences about chemistry including engaging them with inquiry based/investigatory based experimental modules.

NIUS workshops for chemistry teachers are conducted both on-campus as well as off-campus (regular college settings) and the primary aim is to orient teachers with research-based practices in the experimental domain. The duration of each workshop is generally 4–5 days and often around 20–25 teacher participants participate per workshop.

One of the primary objectives of our work was to understand the feasibility of workshops that involve hands-on engagement with experimental modules designed with alternative approaches and understand associated challenges. To the best of our knowledge, such efforts are limited in Indian context but are required. The important question was what approaches should be taken to redesign the experiments for such teacher workshops. Teachers have been conducting lab courses in conventional manner and have no exposure to alternative approaches for lab education. Our experiences in the initial workshops indicated that teachers found it difficult to handle higher levels of inquiry (e.g. problems-based learning) and often new experiments were seen as examples not meant for their own college set-up (possibly meant only for labs at HBCSE). After critical internal discussions within the HBCSE chemistry group, we decided to choose experiments from the UG college lab syllabus for redesigning and look for alternatives that involve lower levels of inquiry. It did take time for us to evolve with these ideas.

Currently, the thrust areas integral to discussion sessions in these workshops are:

- to familiarize oneself with the alternative pedagogical approaches through hands-on engagements
- to reflect on the design of the module to understand the learning opportunities it presents to learners
- to discuss the assessment aspects of the experimental modules
- to identify and reflect on the decision-making opportunities of the experimental module
- to reflect on group/collaborative work in lab setting (teachers perform the experiments in pairs)
- to discuss how such approaches can be adapted in conventional chemistry lab set-up

2 For more information about HBCSE-visit: https://www.hbcse.tifr.res.in/.

One of the major key ideas which we started discussing in these workshops is the need to conduct lab with pre-lab and post-lab components. This approach is relatively an established approach at college set ups in many countries and the rationale for the same has been explained in the CER literature (Agustian & Seery, 2017; Johnstone & Al-Shuaili, 2001; Rodriguez & Towns, 2018). CER literature indicates that pre-lab exercises when designed appropriately can provide opportunities to revisit the necessary background knowledge about the related concepts, techniques involved as part of the experiment, planning of procedure, etc. and such an engagement often improves students' confidence and motivation. However, in Indian context, this approach is not yet widely used especially for chemistry lab courses in university affiliated state colleges. We feel that it is important that this approach needs to be implemented and thus, we have been developing modules using this approach. We selected experiments from the existing UG lab manuals or syllabus. The rationale for the same is that chemistry teachers 'witness' how to use such an approach for their own experiments. It is more approachable for them as they often feel challenged when asked to develop a completely new experiment.

3.1 Initial testing with students for checking feasibility of developed modules

These modules during their developmental stages are also field tested in the NIUS chemistry student camps (and when possible, in regular college setting also) for understanding the feasibility of these modules in conventional lab settings. Students were given experiments in groups (with 2 or 3 members in a group) whereas the instructors (from HBCSE and outside HBCSE) act as facilitators. Students were given briefings about the task at hand. The time available for different parts of the experiment was also communicated to them. However, they were not pushed hard for the time. The facilitator allowed group discussions and then classroom discussion about the answer to the given question. When required, the facilitator asked additional questions, but did not provide the answer directly. Any new skills required for the experiment were explained and demonstrated to students prior to the actual lab. During post-lab discussions, the entire classroom data is presented and discussed critically about the spread in the data, errors, difficulties, followed by analysis and drawing inferences. We did not do quantitative measurements, however, the qualitative feedback by the students indicate that the tasks were engaging (see **Box 8** in the Supplementary). As developers, feedback based on such implementation is equally important for us to revisit our designs.

3.2 Actual workshops with teachers

During the workshop, the pre/post-lab based experiments are implemented in the way they have to be conducted in the actual setting and with fixed time duration. Typically, after engaging in answering the questions in pre-lab, the teacher performs the experiments in the lab followed by solving the post-lab questions. Since we choose experiments from their own lab manuals, teachers did accept that these are suitable for UG chemistry labs. During the workshops, teachers were introduced to the structure of the module and time allocations for different parts. Few facilitators joined different groups initially for sometime to catalyze the discussion within the group. The main facilitator was open to comments and questions received from teachers which helped in making them comfortable. The need to do the experiment by hand was explained to them and classroom data was projected to understand the spread in the data. Post facto, they were asked to reflect on challenges students can face when such a module is implemented in their own college set up.

During workshops, teachers work in pairs and there are intense discussions across pairs. Often, the data across the pairs are pooled and projected which is reflected upon and difficulties faced also are discussed in the larger group discussions. Such a setting help teachers to understand the advantage of group work which is not in practice in conventional lab course in the Indian context. To navigate fruitful discussions in such a setting, the teacher has to take the role of a facilitator which is another important aspect that teachers need to understand. The discussion about the role of teacher as a facilitator is also conducted with them. Once the teachers finish the actual lab work and post lab discussions, there are discussion sessions that primarily focused on the design of the developed modules and their merits/demerits. Teachers are asked to reflect on the concepts involved in the experiment as well as the key ideas related to the design of the given module. They are asked to reflect on the prerequisites for the given experiment and difficulty level of the questions for their students. Teachers discuss the difficulties they might face while implementing the given module in their own college set up.

Another aspect that is deliberated and discussed is assessment scheme of the module. Such discussions are primarily restricted to modules developed using pre/post lab approach. Teachers are asked to come up with an assessment scheme for post-lab questions and the data obtained as part of the experiment given. For example, when the task involved estimation to two ions using titrations, the distribution of marks for each estimation was an area of discussion. Often, they allocate equal weightage without paying attention to the fact whether the given estimation is dependent or independent and which is likely to have more errors associated with it. For example, in estimation of Cu and oxalate for copper-oxalate complex by $KMnO_4$. Molar calculations was yet another difficult area as teachers generally use normal solutions in their own lab set ups. What fraction of marks should be allocated to the quality of data and post lab question was another area of debate. For synthesis based experiments, arriving at sliding scale to deduct marks for deviation in expected yield was a difficult area for teachers. Whenever TLC was included for synthesis experiments, marks to be allocated for quality of developed TLC plate was also an area of debate. Understanding different components of multiple equilibria reaction systems and interpreting plots (e.g. chemical kinetics) was also difficult for teachers and required considerable discussions. With respect to designing, it was difficult for teachers to understand the purpose of framing the pre-lab questions related to the given experiment as compared to the post lab questions.

It is challenging to conduct experimental workshops in colleges. We often choose experiments related to qualitative analysis or titration or organic synthesis domain. These experiments sometimes have to be tweaked as per the infrastructure facilities. However, the issues and problems faced in regular setting act as learning opportunities for teachers to arrive at possible solutions. As designers of experiments, we also become more familiar with issues/problems that exist in regular set-ups which is important feedback for our own developmental work.

3.3 Features of developed modules

General features of the modules developed and standardized are discussed below.

For modules with pre/post-lab components:

- pre-lab questions are related to revisiting requisite concepts, safety aspects, making sense of some important steps of the procedure to be followed, preparing the learner towards making required observations, etc. and has elements of inquiry.
- post-lab questions focus on data evaluation, interpretation of results and observations, drawing inferences, reflecting on errors that may have occurred, reasoning difficulties faced, etc.

In our opinion, designing the existing lab experiments using pre/post-lab approach is feasible due to academic autonomy that is being granted to different state colleges. It is not expecting teachers to radically change the experiment but introduce an important key idea from cognitive load perspective. The pre/post-lab questions of two such modules (one in organic chemistry and another in analytical chemistry) are given in **Boxes 1–2** and **3–4** respectively in the Supplementary. These are primarily developed by chemistry teachers located in the university systems in collaboration with HBCSE members. The pre-lab questions (e,g. acetic acid titration, **Box 3**) provides opportunities to discuss relevant theoretical concepts related to the experiments. Post-lab questions 6 and 7 (**Box 4**) provide opportunities to correlate the change in color and its connection to changes in the structure of the indicator. Students can also test themselves (or it can be demonstrated) that addition of excess base changes the indicator colour back to colorless. These questions provide opportunities to discuss and understand macro-sub-micro connections. Generally, in conventional teaching, less opportunities are provided to build the linkages between observations at macro level and their interpretation in terms of structural changes at sub-micro levels.

For modules with investigatory approach:

This type of module is different from the pre/post lab module and often focuses on developing conceptual and procedural understanding about the domain under investigation. It has several subparts that are linked to different concepts in the given domain. Often the area chosen is relatively less investigated in the regular UG labs though the concepts may be covered in the theoretical domain. Such modules present limited flexibility to plan and/or work out procedural details to conduct a given subpart. The learner has to identify the connections between the sub-parts and make inferences related to an individual subpart as well as from all subparts together. Teachers (and students) have to review the work done and explain the purpose of the investigation, modify/alter plans if significant discrepancy is observed in the data. Such modules require careful design to obtain a fruitful outcome. It may or may not have pre-lab questions depending on the area that is selected for the design. Teachers reflect on the design of both categories of the modules after performing the experiments. This kind of experiment often provides significant opportunities to corelate observations and their interpretation to advance learning and thus, involves deeper levels of inquiry. One of the investigatory modules was exploring estimation of Ca (II) using disodium ethylenediaminetetraacetic acid spectrophotometrically in presence and absence of Mg (II) (**Box 5**).

This module has five different subparts as explained below.

I. Tracking colours of indicator solutions in buffer medium with different pH and overtime.
II. Is Beer- Lambert law valid for indicator solutions at pH 10?
III. Tracking colours of Indicator + metal ion/s solutions in buffer medium with different pH and over time
IV. Study of indicator and Mg (II) ions at different pH
V. Does presence of Mg (II) ions interfere with estimation of Ca (II) in given solution?

Excerpts of sub-part **I** is given in **Box 5**.

Box 5 Exploring estimation of Ca (II) using Na_2EDTA spectrophotometrically

I. Tracking colours of Indicator/s in buffer medium with different pH and over time

In this sub-part, we will explore the solutions of indicators in buffer mediums with different pH (pH = 8, 10 and 12) over a short time period. For the same, we need to prepare solutions in test tubes as described below using the supplied stocks on your table. You will note the color of the solution. **In addition, please take photograph of the solution just prior to the measurement. These photographs will be used for describing colours of the solutions.** You are expected to scan the prepared solutions at time 2 – 3 minutes, 15 minutes and 30 minutes. Note the λ_{max} and the corresponding absorbance (A). The prepared solutions have to be covered using parafilm strips as they have to be stored for the observations for at least 30 mins. The experiment will be performed for only one indicator provided to you on your table.

Note: In some cases, you may obtain more than one λ_{max} and you should report both in the following table.

Solution to be prepared: 5 mL buffer of given pH + 0.2 mL indicator Q + 0.8 mL distilled water

Table I: Study of indicator solutions at different pH

	Buffer = pH 8			Buffer = pH 10			Buffer = pH 12		
Time (t) in minutes	Color	λ_{max}	A	Color	λ_{max}	A	Color	λ_{max}	A
2-3									
15									
30									

Q1. Look at the photographs of the solutions at time t = 2 – 3 minutes for pH= 8, 10 and 12. Do these solutions have same colors when seen by naked eyes? Yes ☐ No ☐

The following table gives the list of wavelengths of absorption and the corresponding predominant absorbed and transmitted color. You will need this table to answer the following questions.

Absorbed Wavelength (nm)	Absorbed Color	Transmitted Color	Absorbed Wavelength (nm)	Absorbed Color	Transmitted Color
400	violet green	yellow	530	green	purple
450	indigo	yellow	570	yellow-green	dark blue
480	blue	orange	600	orange	blue
490	blue-green	red	650	red	green

Box 5 Continued… **Exploring estimation of Ca (II) using Na_2EDTA spectrophotometrically**

Q2. Using the above table and the colour recorded by you in **Table I**, indicate the approximate wavelength that will be absorbed by the solutions at pH = 8,10 and 12 (please answer this question only for solutions w.r.t. t = 2-3 minutes.)

pH 8		pH 10		pH 12	
Color of solution	Wavelength that will be absorbed	Color of solution	Wavelength that will be absorbed	Color of solution	Wavelength that will be absorbed

Q3. Now look at the observed λ_{max} for these solutions recorded in Table **I**. Whether these λ_{max} match with your answers in **Q2**.

Q4. For your measurements, what is your conclusion about -

a) Trend in λ_{max} for solutions at different pH.

t = 2-3 mins

t = 15 mins

t = 30 mins

Overall conclusion

b) Using your answers in **4a)**, comment about the trend in absorbance of the solutions at different pH.

Another approach which is evolving is designing experiments where the planning is to be done by the learner. They are given the aim of the experiment and a list of chemicals and glassware available to them. Here, the outcome is not known to the student or to the teacher/facilitator and requires higher order laboratory skills like critical thinking, application of concepts and problem solving for such an activity. One of the representative examples is given in the Supplementary (**Box 6**).

Since 2016, eleven teacher workshops have been conducted with around 200 participants. Some of the representative feedback obtained by teacher participants is given in **Box** 7. We also have feedback from UG students who performed such experiments to understand how they perceive such modules (refer to B**ox 8** in the Supplementary) The feedback given in **Box 8** is for two of the modules discussed in the article. i) comparative study on nitration of dinitrobenzene by traditional method and the green route using the pre/post-lab approach and ii) investigatory project based on exploring estimation of Ca (II) using disodium ethylenediaminetetraacetic acid spectrophotometrically in presence and absence of Mg (II). The responses are for questions- a) whether the workshop changed the perception about the way the experiment was designed and performed and b) listing of two learning outcomes in the camp (experimental domain).

Box 7 Representative feedback from teacher participants

- *"It will change my perception while conducting practical sessions with undergraduate students*."
- *"By doing such camps, one can learn things by lab work and by making mistakes*."
- *"Making students do pre & post-lab will help students understand what they have to do & purpose of the experiment*."
- *"Learnt how to conduct experiments in a better way for the current batches of COVID-affected/online batch of students with less practical experiences*."

During these workshops we have observed that teachers are engaged with the experimental module at hand, and they complete the given modules in allocated time. However, they were unsure about the time management if they had to implement the pre/post-lab approach in their own colleges as the syllabus must be completed. Overall, teachers appreciated group work in lab and felt it was beneficial. We have realized that the key ideas, especially w.r.t. to designing of experiments using pre/post lab approach will require sustained interactions with teachers.

For the same reasons, we started interacting with a small group of motivated chemistry teachers (primarily located in the city of Mumbai and Pune) through an online study circle. It involves reading and discussing chemistry education research and development literature. The first theme chosen was related to chemistry lab education (https://nius.hbcse.tifr.res.in/list-of-papers/). This group of teacher participants (number = 9 and from HBCSE = 6) got interested in developing experiments using the pre/post lab approach. They chose their own lab manual experiments and started redesigning them. The development went through various phases from initial designs of questions, deliberation about the same with fellow teacher participants (and HBCSE groups members) of study circle, actual implementation of the initial versions and remodifications based on feedback and difficulties faced especially by students. After closely interacting for a period of almost a year, these experiments are now published in the form of a book.[3]

Over years, we have evolved w.r.t. our understanding regarding the approaches that can be used to develop experiments that may be feasible in the UG laboratories in India, especially in state colleges. It has taken us time to develop such an understanding. For the same, it was important for us to conduct these workshops in authentic settings, whenever possible, to understand the difficulties and challenges involved in these settings. We also realized that teachers are more receptive when their own curricular experiments are selected for redesigning. They are more comfortable with a pre/post-lab approach as compared to investigatory approach. However, they do feel that time management is certainly an issue for them. Overall, today we are more confident that teachers can adopt pre/post-lab approaches for UG chemistry lab education.

4 Conclusions

To shift the teaching-learning practices toward those generating opportunities for learning and decision making in conventional chemistry lab courses at UG level, it is important that we introduce the teacher community to research-based approaches that are feasible in their own lab set-ups. In our opinion, the pre/post-lab approach is a meaningful possible alternative approach for the conventional chemistry lab set-ups. The investigatory approach

3 These are published in the book titled Exploring laboratory experiments in Chemistry through Pre-lab and Post-lab activities, Himalaya Publishing House Pvt. Ltd., Mumbai.

is perhaps more suitable for presenting projects that teachers can offer in their existing set-up using the facilities available to them.

Most importantly, for adopting alternative approaches, they have to shift themselves from conventional mode of the role of teacher to that of facilitator role which is not an easy transition. The workshops have reflective sessions about the same. However, sustained exposure is needed to make such a shift. One positive outcome of our efforts is that a small group of teachers who have been interacting with us for a considerable time have transformed some of their curricular experiments using pre/post-lab approach. These experiments were field tested at developmental stages and some of these are now published in form of book (given in footnote 3).

In addition to our activities under NIUS chemistry programme, we are currently conducting workshops for chemistry faculty members in state of Maharashtra by collaborating with Maharashtra State Faculty Development Academy, an initiative of the state of Maharashtra Government. We are slowly expanding this activity, and we do go out of HBCSE to local colleges as the academic system is becoming more open and receptive. Another dimension that we are trying to integrate in these workshops is engaging teachers with some literature reading in CER. Such a step will familiarize them with key ideas/examples of alternative research-based approaches. However, we are still evolving to engage practitioners meaningfully with the same.

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