National Initiative on Undergraduate Science programme in chemistry

*Indrani Das Sen and Savita Ladage**

The article discusses the National Initiative on Undergraduate Science (NIUS) programme in chemistry conducted by the Homi Bhabha Centre for Science Education (TIFR), Mumbai, which was initiated in 2004. Being located in a science education research and development institution, the programme has made efforts to interact with chemistry teachers and first-year undergraduate students and, thus, is different when compared to similar programmes within the country. The article reviews the key ideas of the programme, its growth and evolution to date and likely directions for its expansion in the near future.

Keywords: Chemistry, national initiative, nurture programmes, student camps, teacher workshops, undergraduate science education.

THE Homi Bhabha Centre for Science Education (HBCSE), Tata Institute of Fundamental Research (TIFR), Mumbai, is an established research and development institution in the science, technology and mathematics education (STME) field in India. It has several key impact programmes aimed at science and mathematics education at different levels. The Vigyan Pratibha (https://vigyanpratibha.in/) programme of HBCSE is targeted towards science and mathematics education at the high school level, whereas the Science Olympiads (https://olympiads.hbcse.tifr.res.in/) are targeted towards higher secondary students. The former programme is primarily meant for teachers (also involves school visits), whereas the latter is meant for students. This article discusses the National Initiative on Undergraduate Science (NIUS) programme (and chemistry in particular) that is aimed at the undergraduate (UG) phase of science education.

In the Indian context, science (chemistry) education at the UG level is presented as a 'done' domain and lacks enriching experiences, especially in state colleges. The UG education is teacher-centred and is dominated by conventional instructional and assessment practices. This is even more true for laboratory education. However, the UG phase is important when learners can build a sound understanding of the discipline by engaging in vibrant academic experiences. It is equally important that learners be given opportunities to reflect on their understanding through self-directed learning.

The UG-level teachers often do not have an educational degree (like a B.Ed.) and, thus, do not have exposure to pedagogical dimensions. They must be oriented towards research-based innovative pedagogical practices, and instructional material is equally important. Discipline-Based Educational Research and Development (DBERD) is an established field globally today. It is aimed at systematically investigating learning focused on specific disciplines like astronomy, biology, chemistry and physics. It is grounded in the modern theories of learning and instruction. The awareness of DBERD work is important, especially for practising teachers to change their instructional and assessment practices. NIUS is one such programme trying to expose teachers to the same.

Several scientific institutions across India like the Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Indian National Academies, Indian Institutes of Technology (IITs), Indian Institute of Science, Saha Institute of Nuclear Physics, TIFR and Indian Institutes of Science Education and Research (IISERs) offer summer fellowships or visiting students' research programmes to students predominantly from the second or final year of UG education. One of the important programmes open to first-year UG students to stimulate their interest in science is the Project Oriented Chemistry Education (POCE) or Project Oriented Biology Education (POBE) offered by JNCASR[1]. These present opportunities for UG students to gain first-hand experience in the research areas/facilities within the country and present enriching experiences about the domains of science. Such programmes are of great significance as they can help bridge the gap between research and the UG phase, especially for students from state colleges affiliated with the university system.

The NIUS programme was launched by HBCSE in collaboration with TIFR (Mumbai campus) and Bhabha Atomic Research Centre (BARC), Mumbai, in 2004. However, the development of infrastructure facilities, especially laboratories and hostels for accommodation, took time, and the

Indrani Das Sen and Savita Ladage are in the Homi Bhabha Centre for Science Education, Tata Institute of Fundamental Research, Mumbai 400 088, India.
*For correspondence. (e-mail: savital@hbcse.tifr.res.in)

programme started expanding around 2009–10. At its inception, the programme addressed two major concerns: the declining number of meritorious students opting for B.Sc. courses and the lack of opportunities for motivated B.Sc. students for serious engagement with the subject[2]. The idea of the NIUS programme was not novel compared to the ongoing nurture programmes offered during that time by different bodies, but it perhaps differed in terms of scale, intensity and coverage[3], as it was offered in physics, chemistry and biology with the idea of the extended nurture of the selected students in the form of projects for two years.

The key idea of the NIUS programme has been to nurture promising first-year UG students through sustained mentoring and by engaging them with proto-research opportunities[3]. Along with mentors from TIFR and BARC, the programme involves researchers from other scientific institutions across India. Engagement with a project and sustained mentoring can help UG students gain epistemic knowledge of an expert in a discipline-specific area and develop general scientific skills and practices. The programme has been running successfully for years and is well-established within the country. The necessary details about the NIUS programme offered in biology, chemistry, physics and astronomy are available at https://nius.hbcse.tifr.res.in/. The evolution of the programme differs across these subjects, primarily due to the type and nature of project areas/activities offered.

This article analyses the growth and evolution of the NIUS chemistry programme, which is open to students enrolled for integrated M.Sc. and conventional B.Sc. courses all over India[4]. However, the programme makes more efforts to accommodate B.Sc. students, and to date, students from colleges located in urban and semi-urban areas have participated in the NIUS camps. Often, colleges in the interior parts of India (even in urban or semi-urban regions) are not well equipped with laboratory infrastructure, and the laboratory experiences available to UG students are limited. The teaching–learning practices in such colleges are often conventional. Thus, it is important to have programmes like NIUS, especially open to students from state colleges, to provide them with enriching experiences, especially in the experimental domain.

If one critically examines chemistry education, especially at high school and higher secondary level, it becomes abstract in nature, and both teachers and students struggle to understand and communicate this abstract dimension. In addition to content overload, students do not get enough opportunities to explore various materials and observe their properties (descriptive dimension of chemistry). The symbolic dimension of chemistry is also equally challenging to interpret. As a result, chemistry is perceived as a boring subject at the school level. It will not be wrong to say that students enter their UG phase of education with a negative perception of chemistry (which probably is not the case in biology and physics). Thus, presenting enriching experiences about chemistry is important at the UG level.

Being located in an educational institution, one of the characteristic features of the NIUS chemistry programme is the flexibility it offers in terms of projects. Some of the projects offered are in the core domains of UG chemistry experimental courses and are primarily aimed at developing students as independent learners/investigators. Such projects are more research-like scenarios where students are central to the knowledge-generation process[5,6]. Our experiences show that this approach helps the students open up, as it shifts them from the role of the mechanical verifier of facts (especially in the laboratory context) to that of decision-makers. In our opinion, the availability of sufficient time to engage with an idea, the closeness of the project to domains familiar to the students, sustained mentoring, and ownership of the knowledge trigger their interest and engagement in chemistry.

In the initial phase of the NIUS chemistry programme, it was important to identify some of the core areas for projects that could be done by first-year UG students. The two major experimental areas identified were (i) green routes for organic synthesis and (ii) interfacial chemistry. Green approaches to organic synthesis are a significant area in the chemistry laboratory curriculum of UG and postgraduate (PG) courses and an important area in chemistry education. Another advantage of selecting the area of organic synthesis was that some of the promising chemistry teachers from local colleges of Mumbai and Pune could join as mentors for guiding projects in this area. Involving teachers oriented them on how to conceptualize projects that could be done in their colleges to enhance learning. Interfacial chemistry is an interesting and interdisciplinary area as it relates the concepts in physical chemistry to a number of applications, e.g. action of soaps/surfactants, emulsions/microemulsions, extraction of metal ions, understanding the phase diagram of the three-component system and cloud-point determination. Additionally, computational chemistry was included as a third area as it is equally important for chemistry education at the UG level.

Over the years, the areas of the projects offered have expanded and diversified as more resource persons from different institutions have joined as mentors for this programme. Currently, along with mentors from HBCSE, the NIUS programme has mentors from TIFR (Mumbai campus), IIT Bombay, Institute of Chemical Technology, Mumbai, National Chemical Laboratory, Pune, IISER Pune, Savitribai Phule Pune University, BARC (Mumbai) and a few colleges affiliated to Mumbai University. Some of the representative project areas (core and advanced) given to students include synthesis of organic compounds using different catalysts and energy sources, solvent-free reactions, green solvents, multi-component reactions, phase diagrams, study of equilibria of azo dye/acid–base indicators, measurement of critical micellar concentration of surfactants, extraction of metal ions using the surfactant–ionic liquid system, study of quantum dots, study of the formation of noble-gas compounds having conventional bonding systems, catalysis using

nano-sized noble metals like gold/silver, studies of hydrated electrons in water, hydrated clusters of halo acids, and modelling studies on the anomalous behaviour of water.

NIUS camps for students

Every year, the NIUS chemistry cycle starts in December with an exposure-cum-enrichment camp, which is offered to about 50–55 UG students across India for ten days. The number is restricted due to accommodation constraints. The conception of this camp has a bearing on some of the core issues related to chemistry education at the UG level, as highlighted earlier in this article. The primary purpose is to help students change their perceptions about chemistry. The theoretical content discussions in the camp are in the core (thrust on conceptual understanding) and advanced (enriching experiences about how fundamental concepts are applied to frontier domains) areas of chemistry. The process of questioning and the use of inquiry-based approaches are central to the workshops and laboratory work offered in these camps, which are group activities. Such a participatory student-centred environment nurtures diverse skills like communication and leadership skills, in addition to enhancing their understanding of the subject. Some of the group activities include reading papers related to experimental work (primarily from the *Journal of Chemical Education*, *JCE*), learning concepts using instructional material based on a guided inquiry learning approach (involving self-directed learning), designing and performing investigatory or inquiry-based experiments, and finally writing an abstract for the papers read. The experimental sessions in the camp use the prelab–lab–postlab approach. The experimental modules and instructional materials used in these camps have been developed by members of the Chemistry Group of HBCSE, who are acquainted with chemistry education research (CER), along with the participation of a few motivated teachers at the UG/PG level. The developed experimental modules are field-tested in the NIUS camps for student feedback. Some enrichment sessions deal with topics like the introduction to discipline-based educational research, gender issues related to science, waste generation and its disposal and historical perspectives on topics in chemistry. At the end of the first camp, around 20–25 students are selected for projects to be conducted during three successive vacations (summer, winter and summer, i.e. three project camps). Prior to initiation of the second camp (i.e. project phase), the selected students are required to complete the following tasks (in distance mode), viz. literature review and planning of the next phase of their work (experiment). In the subsequent second and third project camps, students perform several experimental trials, analyse the results, prepare an interim and final report, and submit the same for evaluation to the respective mentors. From 2004 to 2022, the programme was offered to 791 students. The total number of projects completed till 2022 is 145, leading to around 65 publications/presentations in peer-reviewed journals and national/international conferences. During the COVID-19 pandemic, the NIUS exposure camp was held in online mode with sessions similar to those in the offline mode (There was no camp during 2020, while in 2021, the camp was held for second-year students, but no projects were offered.). Table 1 and Figure 1 present representative data for the NIUS chemistry programme from 2015 to 2022. The figure shows that most colleges are from urban and semi-urban areas, with practically no representation from the rural areas. Even in the urban/semi-urban areas, the state-affiliated colleges often do not have the appropriate infrastructure and resources for presenting enriching experiences to the students.

Box 1 provides feedback from the participating students about the exposure camps, while Box 2 provides feedback from students who have completed their projects.

NIUS workshops/camps for teachers

Another significant dimension of NIUS chemistry is workshops/camps for chemistry teachers at the UG level. This dimension will be consolidated further in the near future. Since 2013, 15 teacher workshops have been conducted with around 400 participants. One of the important areas of R&D in CER is 'learning in the conventional laboratory courses', especially at the UG level. The work done in CER advocates the use of inquiry (open-ended, structured inquiry or guided inquiry)/investigatory approaches, group work and changing the conventional chemistry laboratory education to prelab–lab–postlab mode. The prelab is used primarily to prepare learners about key theoretical concepts/laboratory techniques/planning related to the forthcoming experimental work. In lab, the main focus is to

Table 1. Student data for NIUS chemistry programme (2015–2022)

Course/gender of students	Number (%)
Integrated M.Sc./B.S.–M.S.	108 (25.5)
B.Sc.	316 (74.5)
Total	424 (100)
No. of female students	230 (54.2)
No. of male students	194 (45.8)

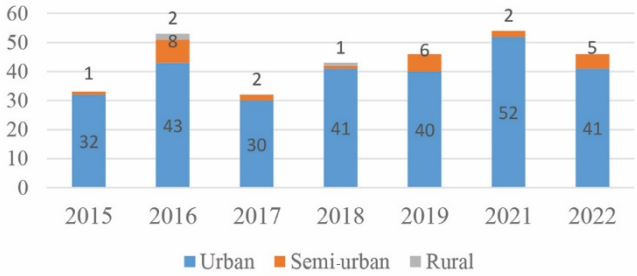

Figure 1. Demographics of college representation National Initiative on Undergraduate Science (NIUS) chemistry (2015–22).

perform the task, whereas postlab provides opportunities to reflect on the data generated, difficulties encountered and understanding the significance of the procedural steps. The CER literature indicates that engagement with prelab has been beneficial to the learners[5,6]. The laboratory sessions in the teacher workshops also use the prelab–lab–postlab approach. Chemistry teachers, especially from various state colleges in India, need to be aware of such approaches and the associated CER literature to bring changes in the existing chemistry laboratory education. Some representative feedbacks from teachers are given in Box 3.

Box 1. Feedback from students in NIUS exposure camps

'The laboratory sessions were mainly thought-provoking and made us not ignore whatever weird results we used to obtain during the experiment.'
'The experiments which I am used to are always successful. The experiments, however, also throw lights over the fact that failed experiments and the values are equally important.'
'I learned to handle a few apparatus and how they worked in the lab. I also learned why specific reagents were used and also their alternatives. I learned what to observe during the experiment.'
'The way we learnt chemistry. The freedom we had in labs and the responsibility of completing the task on time. The new friends, the discussions on sciences and non-science topics. The concept of acceptance of our errors and analysing them, as well as the need to speak up and defend your opinion/about your work.'
'It encourages more that we should go through with all the reactions by questioning ourselves "why" and "How" did it go like that. It boosts our knowledge.'

Box 2. Feedback from project students

'The whole period of the internship at NIUS has been a privilege for me. It has been a great place to overcome my flaws and explore the unknown facts, a great place to boost up and gear up for the future.'
'NIUS gives a very good opportunity for students to get acquainted with the research environment. Contradictory to the other popular programmes, its long duration of project work, which is extended over two years, gives ample time for the students to get a deep understanding of his problem in particular and his field in general.'
'NIUS is the best research programme for Regular BSc students like me who do not belong to scientific institutes like IISER, NISER, etc. Also, NIUS has changed my perspective towards chemistry.'
'NIUS is the best thing that could have happened to me in my Undergraduate life. The overall ambiance of HBCSE was perfect to start our research work, and throughout my stay, I met some amazing people who never made me feel away from home.'

During the camps for teachers, inquiry-based/investigatory experimental modules developed by the HBCSE Chemistry Group members are critically discussed with respect to their contents and pedagogical aspects. Teachers perform experiments in the laboratory to determine the quality of data obtained, problems faced (if any), significance of the procedural steps and obtain first-hand experience regarding the approach. Teachers discuss the experiments from assessment perspectives. Some of the representative modules developed and conducted in teacher/student workshops are uploaded on the chemistry education website of HBCSE (https://chem.hbcse.tifr.res.in/resources/resources-by-hbcse/experiments/).

Another important area covered in the teacher workshops is the Process Oriented Guided Inquiry Learning (POGIL) approach[7]. This approach uses critical questioning to develop conceptual understanding. In POGIL, the teacher takes on the role of a facilitator, and the concepts need to be internalized by engaging with instructional material with a series of critical questions that must be answered through group work. The thrust of these workshops, which essentially had teachers from Mumbai, Pune and Ahmednagar participating, has been to orient them to the key educational ideas of POGIL. In addition, teachers are also engaged with the instructional material and its implementation. Participation in POGIL workshops has motivated some organic chemistry teachers from local colleges to field test the instructional material in their classrooms. The objective was to understand whether POGIL will work in a typical classroom set-up and the associated challenges one may face, considering that group work is an essential component of this pedagogy. One major challenge the teachers reported was taking on the role of a facilitator instead of a conventional teacher. The results of the study have been published in this journal[8]. With encouraging experiences, the teachers started developing activities for understanding concepts in organic chemistry and field-tested them in the NIUS chemistry camps. Currently, a book based on these activities is in press. It is essential to generate such instructional materials involving teachers.

Conceptual pitfall/misconception is another major area of work in CER. Awareness about conceptual pitfalls

Box 3. Feedback from chemistry teachers

'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.'

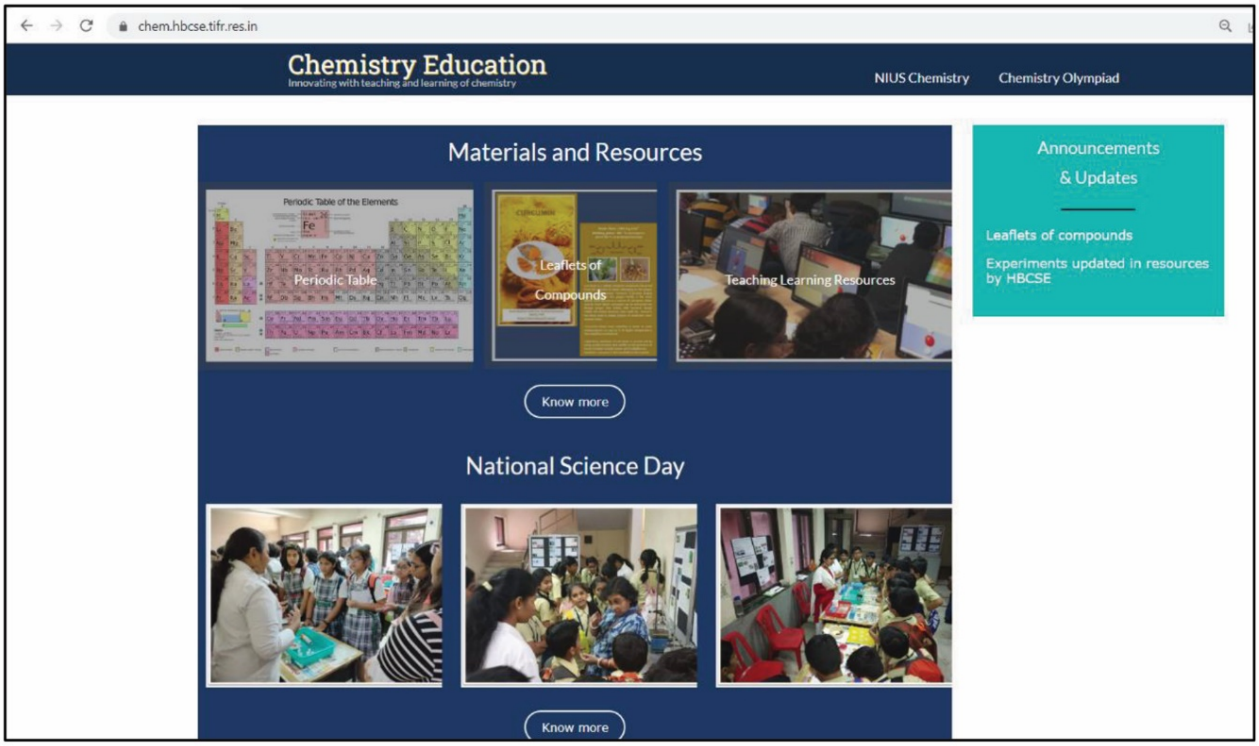

Figure 2. Screenshot image of the chemistry education website hosted on the Homi Bhabha Centre for Science Education platform.

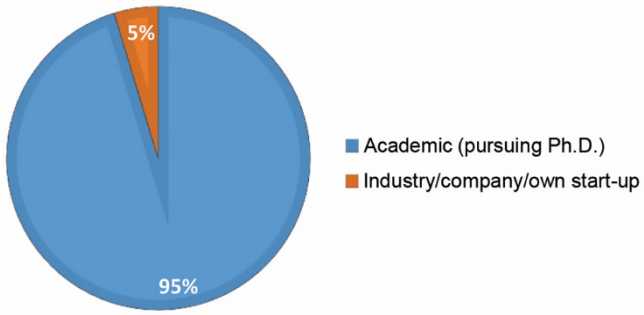

Figure 3. NIUS chemistry alumni record.

provides useful insights for teaching–learning concepts in chemistry in general. It is essential to deliberate about this area with the chemistry teachers. A book related to conceptual pitfalls of learners related to concepts of chemical thermodynamics has been brought out and is available online for reading on the NIUS chemistry website (https://nius.hbcse.tifr.res.in/chemistry/basics-of-chemical-thermodynamics/).

Study circle for chemistry teachers

Since September 2021, a weekly online study circle has been initiated as part of the NIUS chemistry programme. This activity aims to familiarize UG teachers with the literature related to the R&D work done in CER. The sessions covered so far include: (a) literature related to critical questions with respect to learning in conventional laboratory courses, alternative approaches proposed and attempted, associated key ideas and research associated with the same, and (b) reading papers (primarily from *JCE*) related to innovative laboratory courses/experiments based on ideas proposed by CER implemented in the chemistry laboratories at the UG level (readings done by the participating teachers). Such engagement familiarizes them with how experiments are designed in a novel way, associated learning objectives, how experiments are standardized, the type of data collected in the process of development and how they are collected, how the rubrics are developed for assessment of laboratory reports, feedbacks, pre- and post-lab questions, etc. Some of these teachers are currently developing pre/post-lab questions for experiments from the existing laboratory manuals and also discussing the same during the study circle sessions. Overall, these teacher participants (though a small group) are deeply engaged with novel approaches to chemistry laboratory education and the theoretical underpinning (rooted in theories of learning) for the same, the challenges involved, possible directions for developing meaningful laboratory experiments with pre-/post-lab approach, etc.

The Chemistry Group at HBCSE has developed a website to raise awareness regarding the field of chemistry education research and development (The Chemistry Group of HBCSE, in collaboration with the Association of Chemistry Teachers, hosted an International Conference on Education in Chemistry in 2010 and 2014 that was well received

by the chemistry teachers' community (https://associationofchemistryteachers.org/icec.htm)). It highlights the information related to research groups across the world who are active in this field, the established conferences, journals devoted to the field, access to the CER webinars available on YouTube, etc. In addition, the website has a collection of standard open teaching–learning resources as well as those developed by HBCSE (https://chem.hbcse.tifr.res.in/). One of the latest resource development efforts by HBCSE is leaflets related to interesting chemical compounds (available in English, Hindi and Marathi). Experimental modules for the UG level are uploaded on the website (https://chem.hbcse.tifr.res.in/resources/resources-by-hbcse/experiments/). Figure 2 shows a screenshot of the website.

The ground realities about chemistry (science) education at the UG level have changed in India in recent years. The COVID-19 pandemic has also significantly affected the field of education. Thus, the NIUS chemistry programme needs to evolve differently in the near future to impact chemistry education at UG level. As the programme is conducted by an educational institution like HBCSE, it is important to scale up activities for chemistry teachers. Orientation towards discipline-based education research (DBER) areas and associated development activities should take centre stage, as it is the need of the hour. It should also present opportunities for promising teachers to take up projects in DBER-related areas.

Conclusion

Over the years, efforts have been made to develop the NIUS chemistry programme as a multi-dimensional educational activity. The programme caters to promising UG students on the one hand and chemistry teachers on the other. The alumni record of NIUS students who have done projects indicates that a good fraction of them (especially from state colleges) are in academics (Figure 3) (https://nius.hbcse.tifr.res.in/subjects/chemistry/alumni/). It is encouraging to note that these students have taken up a career in science and primarily in academics/industry.

In the near future, it is important to present an in-depth orientation in the experimental domain to UG students. NIUS chemistry is currently exploring possibilities to help enhance the understanding of the camp participants regarding concepts related to the experimental domain. Adapting mini-project mode for experiments and orientation regarding instrumentation techniques in chemistry are a few aspects that NIUS chemistry is currently dealing with. Overall, students must enhance their scientific skills and decision-making abilities related to the same.

Currently, various state colleges are getting academic autonomy and, thus, have the freedom to frame their academic courses. Additionally, due to schemes such as Pandit Madan Mohan Malaviya Mission of National Mission on Teachers and Teaching[9], there is more sensitization and preparedness among chemistry teachers at the UG level towards issues related to teaching–learning processes and pedagogical innovations. In light of this situation, practising teachers must be informed of the work done in the field of CER (or physics/biology education research). With such awareness, at least some chemistry teachers are likely to step into the fertile field of chemistry education research and development. As CER integrates the pedagogical and content dimensions, it is an essential step for impacting the teaching–learning practices integral to chemistry education at the UG level.

1. https://www.jncasr.ac.in/academic/fandeprogrammes/ (accessed on January 2023).
2. Position paper on retention of talent; http://www.psa.gov.in/sites/default/files/file6.pdf (accessed in October 2014), but not accessible now.
3. https://nius.hbcse.tifr.res.in/nius-proposal-2004/ (accessed on January 2023).
4. https://nius.hbcse.tifr.res.in/subjects/chemistry/ (accessed on January 2023).
5. Barke, H. D., Harsch, G. and Schmid, S., *Essentials of Chemical Education*, Springer-Verlag, Heidelberg, 2001.
6. Goedhart, M. J., Finlayson, O. E. and Lindblom-Ylänne, S., Research-based teaching in higher level chemistry education. In *Innovative Methods of Teaching and Learning Chemistry in Higher Education* (eds Eilks, I. and Byers, B.), Royal Society of Chemistry, Cambridge, UK, 2009, pp. 61–84.
7. https://pogil.org/ (accessed on January 2023).
8. Carneiro, G., Parulekar, T., Shridhar, G. and Ladage, S., Experimenting with the teaching of organic chemistry – the process-oriented guided inquiry learning way. *Curr. Sci.*, 2016, **111**, 1152–1155.
9. https://nmtt.gov.in/aboutus (accessed on February 2023).

ACKNOWLEDGEMENTS. We thank all the teachers, researchers and resource persons from different institutions across India (and abroad) who have been supporting the NIUS chemistry programme over the years in various capacities. We acknowledge the active participation of all students in the NIUS chemistry camps. We also thank the Department of Atomic Energy, Government of India, for support (project identification No. RTI4001).

Received 13 February 2023; revised accepted 24 July 2023

doi: 10.18520/cs/v125/i8/831-836