# Experimenting with the teaching of organic chemistry – the process-oriented guided inquiry learning way

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*Undergraduate students tend to find organic chemistry rather challenging and we as teachers of the subject are constantly trying to find new ways to enthuse students and help them understand and enjoy the subject. Active learning has taken centre stage today and one such student-centric teaching strategy, process-oriented guided inquiry learning has been explored by us. In this article we present our experience, the advantages of this teaching methodology and the likely challenges in implementation.*

**Keywords:** Active learning, organic chemistry, resonance, student-centric teaching.

THE teaching of chemistry in undergraduate classes is usually limited to the traditional lecture method. Such classrooms are often teacher-centred and thus students assume a passive role. They seldom get an opportunity to engage with the learning process and develop critical thinking/understanding in these classrooms. Our responsibility as teachers is confined to preparing and delivering 'good' lectures and we have no realistic check on the students' understanding of what is being taught. In our experience, this passive learning results in students becoming unreceptive and slowly losing interest in the subject matter. The gap in teachers' perception of good teaching and actual student learning becomes evident only in the students' answer papers that are sometimes very disappointing.

With this background experience, we realized the need to modify our teaching practices. Research in chemistry education has shown that active engagement of the students in the learning process is useful and results in more meaningful learning[1]. The literature reports several interactive teaching methods such as peer-led teaching learning (PLTL)[2], process-oriented guided inquiry learning (POGIL)[3], PBL (problem-based learning)[4], flipped classrooms[5], etc. We had the opportunity to attend a workshop on the POGIL approach by Kelly Butler (Chestnut Hill College, Philadelphia, USA) at Homi Bhabha Centre for Science Education (HBCSE; TIFR), Mumbai in August 2013. After the workshop, we felt that this approach could be tried out in our setting to actively engage students in the classroom and sustain their interest. The workshop triggered discussion about POGIL amongst us and in June 2014 we, a group of teachers from local colleges of Mumbai, initiated some preliminary work related to POGIL. Further, at the second International Conference on Education in Chemistry (ICEC-2014), hosted at HBCSE (TIFR) in December 2014, we had the opportunity to have close interactions with Rick Moog (Franklin and Marshall College, Lancaster, USA), who is currently Project Director for POGIL.

POGIL is a student-centered teaching–learning strategy, wherein students work in small groups on activities carefully designed by the instructor to foster a deeper understanding of course material through a learning cycle of exploration, concept invention and application[6]. POGIL activities focus on core concepts and include information/data on the topic followed by critical thinking questions through which the concept is developed and consolidated. Group work encourages active involvement of every student in the class, and gives them the opportunity to 'teach' and be 'taught' in a supportive group atmosphere. Students in each group are assigned individual roles of manager, recorder, spokesperson, etc. to ensure that all of them while being engaged in the learning process simultaneously develop key process skills such as analytical thinking, effective communication, team work, time management, etc. The instructor serves as a facilitator, observing and periodically addressing individual and classroom-wide needs. The POGIL method basically uses discipline content to facilitate the development of higher-level thinking skills and the ability to learn and apply knowledge in new contexts.

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The main objective of the exploratory study we undertook from June 2014 was to examine the feasibility of the POGIL methodology in regular undergraduate classrooms from local colleges in Mumbai. Other aims were to gather first-hand experience regarding the difficulties faced both at the students' and teachers' end while implementing cooperative learning and to see whether the use of such material affects the understanding of the concepts. We were also interested in checking how the guided enquiry content (POGIL material) would be perceived by students from our traditional set-up with varying academic backgrounds.

## Outline of the study

Since we were going to experiment with the POGIL methodology in conventional classrooms for the first time, we decided to use standard POGIL instructional material for our study. After going through various available resources, we selected POGIL activities from *Organic Chemistry: A Guided Inquiry*[7]. The topic chosen for POGIL study in organic chemistry was 'resonance', primarily because it is a core topic for understanding the structure and reactions of organic compounds. Further, it is a topic revisited several times during undergraduate (UG) courses and our teaching experience indicates that students perceive this topic to be difficult.

After detailed discussions, we felt that 'Lewis structures' and 'formal charge' are pre-requisite concepts for 'resonance' and thus decided to include POGIL instructional activities related to these topics in a pilot study (Table 1). While going through these activities, we realized that the activity sheets needed modification in terms of language and content to suit UG students in India. Thus, we partly modified the activities and decided to pilot test them on small groups of students.

The activity sheets related to 'Lewis structure' and 'formal charge' were used in a pilot study. Both these areas are generally introduced in chemistry syllabi at class XI/XII. The pilot testing was conducted in two different colleges by two different researchers (G.C. and T.P.) involved in the study. Students were briefed about POGIL and participation in the pilot study was voluntary. The sample of students in the pilot study was representative of a typical UG class from any local college of Mumbai. After the pilot testing, students were asked to fill in the feedback form about the activity. In addition, researchers interacted personally with some of the participants for more detailed feedback, particularly about content and language of questions and the changed role of the teacher as a facilitator.

The feedback from the pilot study was helpful in planning the final study. Some of the feedback comments made by students are as follows:

- The group discussions and peer teaching were valuable to improve understanding, and enthusiastic interaction among members of various groups was helpful.
- Some questions were unclear because of the language and some of the questions were too lengthy. However, attempts were made to answer every question.
- It was necessary to seek the teacher's help while solving some questions.

On the basis of students' feedback and our observations, the activities were further modified in terms of content, language and overall length. Particular care was taken to reframe the questions that needed the teacher's help. With respect to content, the recognition of formal charge was proving to be a stumbling block for students, and hence some questions and examples in the build-up of the concept were reframed.

Two subject experts then validated the revised material with respect to content. An important suggestion from the content experts was related to inclusion of several different concepts in an activity, and they suggested avoiding the same. The material was further modified according to this suggestion. Table 2 summarizes the structure of the final instructional material used.

The final POGIL expository study was then carried out at three different colleges. Since the study aimed to understand the challenges experienced by students and teachers, we selected one college where students generally had an average performance on regular chemistry tests. The second sample consisted of students whose selection in the UG course was through a standard all-India entrance test, and the third sample consisted of students with a mixed background. Table 3 provides details of the final study.

**Table 1.** Pilot study

| College I | College II |
|---|---|
| First-year UG | Second-year UG |
| Four groups of three students each (only girl students) | Four groups of three students each (both girls and boys) |
| Over two days | Over two days |
| Duration of session: 1.5 h/day | Session: 1.5 h/day |
| One teacher | One teacher |

**Table 2.** Brief description of the POGIL activities used

| Lewis structure and formal charge | Resonance |
|---|---|
| Two units (21 questions) | Two units (29 questions) |
| Seven questions (drawing Lewis structures, identification of wrong Lewis structures) | Nineteen questions (drawing curved arrows and resonance structures, identification of illegal curved arrows, choosing major and minor resonance contributors) |
| Fourteen questions (calculation of formal charge, assigning formal charge to atoms, completing Lewis structures and then assigning formal charge) | Ten questions (understanding resonance stabilization, lowered potential energy of species) |

**Table 3.** Final study

| Sample | I | II | III |
|---|---|---|---|
| Number | 31 (second year UG) | 27 (first year UG) | 32 (first year UG) |
| Students | Local college/average performance in regular chemistry tests | Local college/above average performance in regular chemistry tests | From Institutions/colleges across India |
| Entry to the course | Entry on the basis of marks obtained in class XII | National-level entrance test for admission | – |
| Group formation | By researcher (students of varied ability) | Groups formed by students | By researcher |
| No. of groups and gender | Three (all girls), 1 (all boys) and 7 (mixed) | Five (all girls), 3 (all boys) and 1 (mixed) | Four (all boys), 1 (all girls) and 4 (mixed) |
| Classroom setting | Rearranged for group work | Regular classroom setting | Rearranged for group work |
| Number of days for POGIL activities | Four days – one lead facilitator + two additional researchers as observers | Two days – one facilitator (one of the researchers) | Two days – one lead facilitator + two additional researchers as observers |

## Impressions from the POGIL final study

Conducting the POGIL study on three differing groups of students helped us develop a feel for how the method would work with different groups of students. As mentioned earlier, sample I primarily consisted of students with average performance in regular class tests and who face some difficulty with respect to English. For this sample, one of the present authors (G.S.) was the facilitator who was responsible for interacting with all groups. However, two other authors (G.C. and T.P.) were involved with observing the entire classroom dynamics, and all three recorded their observations independently. These recorded observation sheets were compared post facto and cross-validated. All three teachers observed excellent group interactions and found all groups engrossed in the POGIL activity at hand. They noticed that often within a group, some students took the lead to explain things when the group was struggling to understand a question. These students had difficulty in understanding terms like 'legitimate', 'hetero-atom', 'major' and 'minor' resonance structures and instructions like 'confirm that the following structures are correct'. It was observed that simple questions on the understanding of the topics were answered. However, application questions involving finding errors in structures were frequently left blank/answered incorrectly. All the observers felt that interactions in each could be monitored effectively because of the presence of three teachers during the conduct of contact sessions. From the facilitator's point of view, it was challenging to shift from the familiar role of a teacher to that of a facilitator. Also, the observers had to make efforts not to interfere with group interactions.

In the case of sample II, one facilitator conducted the entire activity in a shorter time (anticipating that good students would take less time to complete the activity) and there was no observer in the class. This was planned, as it would be the typical future scenario as far as UG POGIL classes are concerned. In this sample, it was observed that students were competitive (wanted to finish ahead of time) and tried to solve problems individually rather than interacting in the group. Initially, the facilitator had to prod them to work as a group. She felt that monitoring group interactions adequately in each group was difficult and the activities were rushed through.

For sample III, once again there was one facilitator and two observers. It was observed that the interactions were adequate and there were no issues with respect to time and language.

The overall performance of students in samples II and III was good, though some of the questions were not attempted. These students did not face any problems with language in the questions.

Student feedback showed they appreciated cooperative learning. Students, particularly in sample I, thought that peer interactions were useful. All students felt that the activities were interesting and their perception was that the POGIL questions helped them understand the concepts.

As teachers, our involvement during the six-month duration of study was educative and thought-provoking. We gained enriching experience about both the instructional material and the methodology. The overall positive feedback by students (particularly from sample I) has convinced us that POGIL is implementable in regular classrooms. However, managing a large class (of more than 40 students) is challenging for a single facilitator. We felt that teachers themselves would benefit from the training so as to get comfortable in a role where they facilitate the discussions rather than provide direct answers. To assist learning, POGIL activities need to be introduced for longer periods and for various topics, so that students are more at ease with this learning methodology and can really profit from it. After longer intervention, it will be meaningful to see how it affects learning.

Our effort to modify the standardized POGIL instructional material was an equally enriching experience for us. During this process, we were forced to think about the concepts, their sequence, the pre-requisites needed, background information to be given to students, careful designing of questions with examples, sequence of questions, application questions to be used to reinforce learnt concepts, etc. Analysis of the answered POGIL material sheets also gave us important insights into students' difficulties/misconceptions. We realized that students found it difficult to count electrons for completion of octet of an atom and subsequently decide the charge on the atom. They generally tend to confuse completion of octet with the number of electrons on a charged atom. We were surprised to find that students did not use odd electrons on adjacent atoms to form multiple bonds. A misconception among many students was that 'benzene existed as constantly interconverting resonance structures'. Noticing these and other errors on the POGIL sheets helped us clarify students' doubts.

## Ongoing work

Currently, the work is continuing and is focused mainly on development of POGIL instructional material pertaining to various topics in organic chemistry from the UG syllabus prescribed by the University of Mumbai. The work is a collaborative effort between HBCSE (TIFR) and teachers from local colleges of Mumbai and Pune, including the present authors. POGIL activities on some introductory topics from the first year B Sc syllabus are being written first. Experts who have experience in designing such instructional material are validating the developed material. The material will be tested in classrooms and then made available either on-line or in printed format to the wider population of teachers/students.

Through our exploration, we realized that as teachers, we started pedagogically reflecting upon the content. Even with a short exploration of six months, directly or indirectly, we have begun reflecting on our own conventional teaching. We strongly feel that UG teaching in regular colleges needs to be changed and opportunities need to be created for active learning by students. In our opinion, if active learning is implemented on a sustained basis, it has the potential to bring desirable changes. A difficulty we foresee is that due to time constraints in completion of the syllabus, there will be resistance to use of such material as such activities are perceived to be time-consuming. However, if these are going to help students internalize the concepts taught, they would be worth the effort involved. We are optimistic that the POGIL methodology can be incorporated into our teaching programme for at least some topics.

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