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In memory of Philip Coppens (1930–2017).

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From the source: student-centred guest lecturing in a chemical crystallography class

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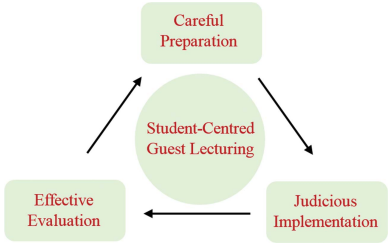
Guest lecturing is an underutilized teaching strategy that provides depth and richness in college-level chemistry courses. The authors have found that student-centred guest lecturing that combines themed guest presentations, hands-on workshops (whenever possible) and small group conversations has yielded tremendous benefits. As a result, students have developed a lasting interest in chemical crystallography and have employed advanced experiments in their own research. The authors report on their experience in planning student-centred guest lecturing, advise on best practices, and demonstrate the long lasting positive impact on student learning and engagement.

1. Introduction

Guest lecturing is one of the most effective ways to improve a class and engage students (Davis, 2009; Ward, 2011; Merle & Craig, 2017). It directly brings experts from the source to the classroom, provides important specific information about subjects that are often overlooked in a regular class, and encourages students to get fully involved in their learning and to think more creatively and critically about their research as a part of the real world (Leor, 2015). However, 'the average college graduate in education has received little if any training in the use of guest speakers' (Ward, 2011). Despite the positive feedback from guest lectureships in the fields of business education (Dalakas, 2016; Davis, 2009; Li & Guo, 2015), to the best of our knowledge, the use of guest lecturing in college-level chemistry courses has barely been discussed. This represents a missed opportunity to expand chemistry students' hands-on learning experiences and to allow them to acquire skills that can be applied to their own research. Our course on chemical crystallography not only provides graduate and upper-level undergraduate students with an understanding of fundamental crystallographic concepts through traditional lectures, but also allows them to collect and evaluate crystallographic data during hands-on exercises (Campbell *et al.*, 2016; Malbrecht *et al.*, 2016). Furthermore, we utilize student-centred guest lecturing (Li & Guo, 2015) to enrich our curriculum by bringing in experts in 'specialty' fields that are not well covered in routine crystallography teaching. We have experimented with and refined the following approaches – themed presentations, hands-on workshops (whenever possible) and small group conversations. Such approaches have become a highlight of the course for our students and



provide the students with exposure to a much broader range of real-life applications of the course material. Students are able to develop a deeper understanding of the opportunities that advanced crystallography (Rissanen, 2012) offers and employ such advanced experiments in their own research. Herein, guidelines are described for student-centred guest lecturing in a chemical crystallography setting, which we hope will be of use to educators in the field.

2. Guidelines for student-centred guest lecturing

The student-centred guest lecturing approach is designed as an active learning experience where students participate at each step of the process, including careful preparation, judicious implementation and effective evaluation (Fig. 1). It maximizes the benefit to students and increases student engagement. Through trial and error, some general guidelines were developed to increase the effectiveness of guest lecturing.

2.1. Timing

A successful student-centred guest lecture requires plenty of advance preparation (Cloud & Sweeney, 1988; Kamoun & Selim, 2007). A carefully selected, well prepared guest provides depth and clarity; therefore, it is important to contact the potential guest lecturers at least two months ahead to begin planning. In our class, we have found that it is best to arrange guest lectures in the final third of the semester. At that time, students have already received a sufficient background in crystallographic theory and practice in structure solution and refinement prior to being introduced to advanced crystallography topics. Such an arrangement also allows enough time for organizers to contact the potential guest speakers. Besides the early planning strategy that allows us to get into the desired speaker's busy calendar, we make sure we build some flexibility into the schedule, and try not to be too rigid about particular dates (Mullins, 2001).

2.2. Choosing guest speakers

Students tend to be more interested in participating in class when they are curious about a specific topic (Li & Guo, 2015). On the first day of class, students are required to identify what their research is, what they want to obtain from this course and what kind of advanced crystallography techniques may relate to their research interests. Such additional, advanced topics are tailored to the students' specific learning goals, with the aim of expanding their awareness of the opportunities that advanced crystallography offers and enabling them to employ complex experimental approaches in their own work. Students usually appreciate the opportunity to provide input about the advanced topics that they would like to understand in more depth. On the other hand, finding a desired guest speaker who can fit into the course schedule may be difficult, so the instructor should not make any promise to students at an early stage (Mullins, 2001). If the class runs on an annual basis, inviting a broader audience (such as those who took the class in previous years and those in the department interested in that particular topic) will greatly increase the impact of the guest lecture.

The guest speakers should play a role in fulfilling a particular learning objective of the course (Mullins, 2001). They could be faculty in other departments or universities, beamline scientists from national laboratories, research scientists from vendors of in-house instruments, or developers of specialist scientific hardware/software, with backgrounds ranging from academia to industry (a list of examples of guest speakers is shown in Table. 1). They should be able to share first hand practical knowledge with students, as the 'source' of an advanced crystallography technique. For example, some students in our course showed great interest in learning about photocrystallography because their research group has been using this technique. Professor Philip Coppens, who coined the word 'photocrystallography' to describe the technique that he developed to observe the transient-state structure of highly photo-reactive molecules (Coppens, 1997), was therefore invited in 2015. Although Professor Coppens had a busy schedule in April (see Fig. S1 in the supporting information), our early planning strategy allowed us not only to get on his calendar, but also to engage him in a feedback process to tailor his presentation toward the learning goals that the students actively pursued.

Finding a credible guest speaker is a trial-and-error process. It is a trivial matter if the guest speaker is a personal friend, or someone known from a conference, in which case their speaking style is already known. Otherwise, the course instructor may have to use a variety of resources, such as referrals from colleagues, to find suitable potential speakers (Mullins, 2001; Wetzel, 2012). If the class is offered every year, it is important to establish and maintain a database of past as well as potential speakers who are willing to participate (Kamoun & Selim, 2007; Wortmann, 1992). Such a database should include the speaker's contact information, their areas of expertise and a summary of students' feedback. Ultimately it is an invaluable tool for identifying the most appropriate and diverse speakers, including those destined for repeat engagements.

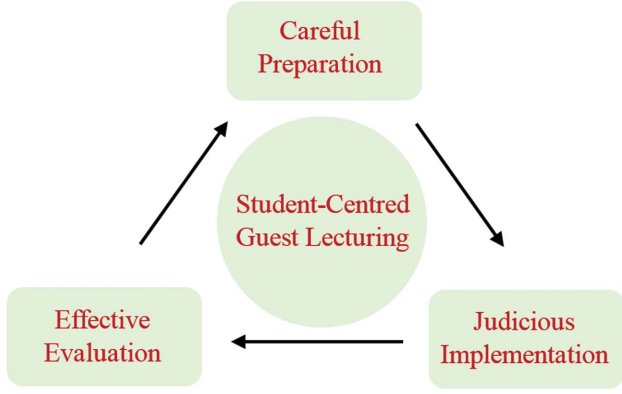


Figure 1
A framework for student-centred guest lecturing.

Table 1
Examples of guest lecturing for advanced crystallography.

Selected slides for themed presentations and tutorial materials for hands-on workshops, as well as our course details, have been made avaliable on the web site *Education & Outreach* (https://chemistry.harvard.edu/pages/education) with permission from their authors.

Guest speaker	Themed presentation	Hands-on workshop
Yu-Sheng Chen (ChemMatCARS, University of Chicago)	Synchrotron Radiation Facility and Advanced Crystallography at ChemMatCARS	
Philip Coppens† (SUNY Buffalo)	Molecules in Motion Studied by Time-Resolved Crystallography	
Bruce Foxman (Brandeis University)	Single-Crystal Reactions and Phase Transitions: Methods, Solutions and Puzzles	
Rachelle Gaudet (MCB, Harvard University)	Data Collection and Phasing for Macromolecular Structure Determination	Phasing for Macromolecular Structure Determination
Bob He (Bruker Inc.)	Basics and Recent Advances in Two-Dimensional X-ray Diffraction	Stress & Texture Analysis on D8 DISCOVER with XRD^2
Christina Hoffmann (ORNL)	Introducing Single Crystal Wavelength Resolved Neutron Diffraction	Beam Time Proposal Writing and Submission
Scott A. Speakman (PANalytical Inc.)	Thin Film Analysis by X-ray Scattering Techniques	Materials Analysis by High Resolution X-ray Diffraction
Anatoliy Volkov (Middle Tennessee State University)	Introduction to the X-ray Charge (Electron) Density Modelling	Tutorial of Aspherical-Atom Refinement with the *XD2006* Suite of Programs
Xiaoping Wang (ORNL)	Neutron Single Crystal Diffraction: Principle and Application in Chemistry and Materials Science	Neutron Structure Refinement – A Tutorial Using *SHELX* for Neutrons
Christina Zimanyi (MCB, Harvard University)	Sample Preparation for Macromolecular Crystallography	Practical Aspects of Cryocrystallography – Methods for Cooling, Mounting and Shipping Crystals

† Deceased.

2.3. Communicating with a guest speaker

Communication between the course instructor and the guest speakers is important for improving the learning experience of the students (Lang, 2008; Leor, 2015; Wortmann, 1992). Guest experts who are not aware of the students' level of familiarity with the material may speak over the students' heads or will not draw from the examples that are relevant to what the students already know. Once a guest speaker confirms the engagement, we communicate clearly with the guest about the objectives of the class and the students' background. A copy of the syllabus and a brief summary of the previous related presentations will be shared with the guest if necessary. The guest experts are encouraged to tailor their remarks towards the specific learning goals of the students. If there are hands-on workshops that follow the lecture, an appropriate tutorial material, as well as pertinent references, should be prepared by the speaker and distributed in advance to each participant (Berrett, 2012).

Keep in mind that the audio-visual setup for lecturing may vary between different institutions, and inform the guest speaker what equipment is available in the classroom. Also, as the day approaches, just in case, double check with the speaker. Prepare a routine lecture in case the guest speaker cannot attend.

2.4. Format and schedule

There are many ways to approach guest lecturing, and we have experimented with and refined the following approaches – themed guest presentations, follow-up hands-on workshops (whenever possible) and small group conversations with the guest speaker.

'Crystallography is the experimental science of determining the arrangement of atoms in crystalline solids' (Wikipedia entry on Crystallography, https://en.wikipedia.org/wiki/Crystallography). Thus, it is important to keep a good balance between theory and practice (Roehrig & Hannum, 1974). For example, students who were interested in neutron diffraction were also interested in learning how to use *SHELXL* (Sheldrick, 2015) to refine a single-crystal neutron diffraction structure. Therefore, a guest lecture with a two-day format was arranged. The routine course presentation on the first day was also included in the department seminar schedule, which is open to the public and advertised on the department web site. The presentation familiarized the audience with the theory and principles of neutron diffraction, and then moved on to the practical aspects of growing and mounting crystals for neutron diffraction, ending with a discussion of what kind of information could be gleaned from these experiments. It was similar to students' regular classroom instruction, but allowed enough time for a question and answer period (Kamoun & Selim, 2007; Wortmann, 1992). Students were required to take notes and prepare questions in advance to ask. The next morning a small group workshop was held in which participants had the chance to practice hands-on refinement of neutron diffraction data. The students who come to such (optional) hands-on activities, usually less than ten people, are expected to read the tutorial material that is distributed in advance and discuss the material during the activities (Berrett, 2012). The ability to learn from an expert something that is not published in modern textbooks offers an invaluable opportunity to modern chemistry students, as often these techniques will form the basis for future research endeavours in their fields.

Additional small group conversations with students (and their principal investigators) are encouraged before or after a guest presentation. For many students, discussion with experts at the edge of their field gives a truer sense of their authenticity: students have read the experiment on paper, and now get to see the person who performed it in real life, interact with them and learn from them directly. These conversations also help contextualize the material that was presented and explain where it can be helpful in ongoing research projects. When working with the department event coordinator, it is also possible to set up meetings with individual research groups in the department. To maximize efficiency and minimize lost time, a series of guiding questions can be provided to visitors in advance, ranging from a broad discussion of possible student questions to active collaboration in their own research project.

2.5. Travel and other considerations

It is important to secure enough funding and resources for the successful completion of guest lecturing (Leor, 2015). Depending on the guests' location, transportation and accommodation are likely to be the most cost intensive aspects. While financial resources differ from school to school, we suggest two possible options for instructors to consider: first, it may be possible to incorporate travel costs into the budget of the course or the department seminar program; second, if the companies or national laboratories where the guest lecturers work have an educational component of their mission, they may provide travel support for their staff to engage in teaching opportunities. In any case, the instructor will need to take advantage of the early planning strategy.

Additionally, be aware of the travel policies and resources for inviting guest speakers (Berube, 2010), particularly those relating to reimbursement. It is extremely helpful to work closely with the event coordinator in the department.

2.6. Post activities

In order to continuously improve this process, it is important to gather anonymous feedback from the students. This can be rapidly achieved using a questionnaire at the beginning of the workshop that is anonymous but asks pointed questions about the guest lecturing (see Fig. S2 in the supporting information). A set of customized questions, including the comments on guest lectures, can also be incorporated into the course's evaluation form (see Fig. S3 in the supporting information) for further reference. With permission from the guest, the presentation slides, as well as the tutorial material, can be given to the students to revisit and used by the instructor in future courses (especially when travel is not possible).

It is important to provide opportunities for further debriefing. We usually retrieve and highlight some key content from the guest lecture in the next class (Brown *et al.*, 2014); therefore, students have another opportunity to review and further improve their knowledge regarding the concepts and techniques that they have learned.

Send your guest speakers a general narrative summary of information from the anonymous feedback along with a thank you note (Mullins, 2001; Wetzel, 2012). The anonymous feedback can also be of use to the speakers during their own performance reviews. If a guest lacks experience speaking to a college class, and has concerns about their lecturing, telling them what worked best can help.

3. Impact

Overall, student-centred guest lectures have increased student engagement and active learning. The focus placed on the 'source' of advanced crystallography techniques allows students to learn what crystallography can do for their research and to network with professionals who can potentially provide a valuable collaboration. Students are typically keen to take advantage of such resources once they become available and apply what they have learned to complete their research projects (Das *et al.*, 2017; Feng *et al.*, 2017; Hwang *et al.*, 2015; Lou *et al.*, 2016; Powers *et al.*, 2013, 2016; Powers, Anderson *et al.*, 2014; Powers, Hwang *et al.*, 2014; Ramadhar *et al.*, 2015*a*,*b*, 2017). A list of example beam time proposals that students submitted for their own research projects at two major user research facilities can be found in Table S1 in the supporting information.

Additionally, the guest speakers can use their expertise to clarify issues that the course instructor may not be entirely familiar with (Berube, 2010; Leor, 2015), and provide the instructor with an opportunity to keep abreast of the latest developments and challenges in chemical crystallography.

3.1. Testimonials

The student response to learning advanced crystallography from student-centred guest lecturing has been quite enthusiastic. Excerpts of reviews from former participants are shown below, and the full texts can be found in the supporting information.

> The guest lecture provided a great opportunity to hear a beamline scientist's perspective on their own field and to ask questions about experimental capabilities, and the workshop introduced us to the basics of the data processing for a simple experiment and emphasized the differences in data processing as compared to a standard X-ray experiment. This inspired me to . . . learn more about . . . techniques that could be very useful for my research. As a result of this experience, I am now planning to apply for neutron beam time . . . (Kevin Anderton, a first-year graduate student from Professor Theodore Betley's group in 2017, currently still a graduate student at Harvard University).

> I found each of these lectures to be valuable additions to the class and really great opportunities to learn more about advanced techniques that expanded on the foundational course material . . . it's exciting to see a direct connection between something you're learning in class, and research being done by leaders in the field. It definitely made me and the other students

in the class more engaged, and eager to think about how to use various X-ray techniques for our own research ... Without the opportunity to learn about these techniques, and to meet the guest lecturers and make valuable connections, I wouldn't have been able to pursue these kinds of directions in my research. And now, at the beginning of my independent research career, I am grateful to have a working knowledge of advanced X-ray techniques that I gained from the guest lectures in Chem255 (Michael G. Campbell, a former student from Professor Tobias Ritter's group, currently an Assistant Professor of Chemistry at Barnard College).

I have benefited a lot from the guest lectures organized in Chem255 ... The broad scope of X-ray crystallography opened by guest lecture series had changed my thesis direction ... the following conversations with Dr He had led to a series important experiments that supported my main findings in my thesis ... (Harbing Lou, a former graduate student from Professor Roy Gordon's group, currently working at T-Mobile Inc.).

Not only did guest lectures during the graduate crystallography course significantly broaden my exposure to advanced crystallographic techniques and modern applications of chemical crystallography, these lectures directly impacted my independent research program ... In large part influenced by attending Professor Coppens's guest lecture on advanced crystallographic techniques, we initiated an effort in photocrystallography and obtained direct structural data related to critical photointermediates. The ability not only to attend the lecture but also to interact one-on-one with Professor Coppens was invaluable to understanding both the theory of photocrystallography as well as the practicalities of executing these challenging experiments ... It is rare that a classroom experience so directly impacts research directions, but the exposure to advanced crystallography through guest lectures significantly impacted the toolbox that my group now uses to understand photochemical processes (David Powers, a former postdoctoral fellow from Professor Daniel Nocera's group, currently an Assistant Professor in the Department of Chemistry at Texas A&M University).

4. Conclusion

We have found that student-centred guest lecturing has yielded tremendous benefits and added significant value to the students' learning experience and achievement of course learning goals. We encourage educators to consider using such an approach more often in crystallography education, because it provides specific knowledge and motivates students to actively engage with experts. As a result, it increases students' ability to use crystallography as a tool in their own research.

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