Pedagogical Inquiry Grant Final Report:

Reimagining Whitman's Organic Chemistry Laboratory Curriculum

Biswas, Collins, Götz, Juhasz

Type B: Departmental Inquiry Project

Overview of Work Performed

The working group met weekly during the fall semester to develop and update the Organic Chemistry Laboratory (Chemistry 251 & 252) courses. Our work began with updating the learning goals for 251/252, which were then used to guide the mapping of key concepts and techniques across both semesters. This was a very useful exercise as it allowed us to identify holes in our coverage and wasteful redundancies (e.g., covering the same technique multiple times). The concept map was used in several cases to revise portions of the new learning goals. At this point, the working group had a lengthy discussion about the possibility of incorporating a unifying theme into the lab courses. Ultimately, we decided not to pursue one, given the constraints it would place on selecting experiments. We decided that the learning goals we had set out would be best achieved by selecting the best-designed and most engaging experiments rather than needing to choose experiments that fit within a given theme. At this point, it became apparent that building a syllabus and selecting experiments for both semesters was infeasible. This led us to focus on developing the first semester lab (Chem 251).

Having established the learning goals, concept map, and general structure of the newly designed Chem 251, we set about developing the syllabus for the course. This took several rounds of discussion. Each week, participants were responsible for gathering potential lab experiments and sharing them with the group. The collection process included requesting materials from colleagues at peer institutions, combing the chemical education literature, and imagining new labs that would be developed here at Whitman. We methodically worked down the learning goals and course structure to slot new labs at points where they would connect to concepts being presented in the lecture course (Chem 245). A theme that emerged from our previous discussions was the importance of having some continuity between labs regarding skills and solidifying concepts taught in prior labs. A common critique of the old labs was that they presented a series of one-off experiments with little continuity. The new lab structure for 251 addresses this critique by incorporating a sequence of modern experiments that introduce laboratory skills and concepts in a progression that intentionally builds through the semester.

New 251 & 252 Learning Goals

The new learning goals resulted from our discussion about what topics should be represented each semester. The goal in revamping them was to strengthen continuity between the semesters and to more intentionally integrate computational methods (something the department has been doing across its curriculum). This is best typified by including a learning goal explicitly related to computational methods in each semester. The integration of computational chemistry also represents a good example of progression between the semesters; rudimentary computational methods and software are introduced in 251 and then greatly expanded upon in 252.

Learning Goals for 251

Students will learn new skills and improve in the following areas:

- Technical skills: Planning and performing reactions of organic compounds, isolating and/or purifying impure mixtures, and characterizing compounds using instrumental and other methods.
- Communication and writing skills: Keeping a lab notebook record of procedures, observations, and data in a format familiar to professional chemists; and representing molecules and reactions using chemistry drawing software; interpreting and writing experimental/method sections.
- Visualization and analysis using computational methods: Use of chemistry drawing software to represent molecules and reactions in professional, publishable formats; application of rudimentary computational methods to answer chemical questions
- Critical analysis: Analyzing the methods used and results of experiments, formulating logical conclusions that are supported by evidence, and communicating this analysis in writing.
- Safe lab practices: Being knowledgeable about laboratory hazards, working in a manner that minimizes risks, and handling chemicals and laboratory equipment in a safe and appropriate manner.

  Participation in the chemistry laboratory is critical to fulfilling the above learning objectives.

Learning Goals for 252

Students will learn new skills and improve in the following areas:

- Technical skills: Planning and performing reactions of organic compounds, isolating and purifying products, and characterizing compounds using instrumental and other methods; planning and performing multi-step synthesis.
- Communication and writing skills: Keeping a lab notebook record of procedures, observations, and data in a format familiar to professional chemists; reporting of experimental outcomes in written laboratory reports; navigating/searching chemical literature and the appropriate citation sources.
- Visualization and analysis using computational methods: Use of chemistry drawing software to represent molecules and reactions in professional, publishable formats; use of more advanced (quantum mechanical) calculations to answer deeper chemical questions related to reaction mechanism and kinetics/thermodynamics.
- Critical analysis: Analyzing the methods used and results of experiments, formulating logical conclusions that are supported by evidence, and communicating this analysis in writing; making meaningful decisions during experimentation that are based on collected data/observations.
- Safe lab practices: Being aware of laboratory hazards, working in a manner that minimizes risks, and handling chemicals and laboratory equipment in a safe and appropriate manner.

  Participation in the chemistry laboratory is critical to fulfilling the above learning objectives.

New List of Experiments for 251

The following is the draft outline for the redesigned 251 course. Only one experiment from the previous Chem-251 course has been retained, making this an almost complete redesign. The experiments represented here were selected based on their ability to provide more continuity between labs, engage

Chem 251 - Lab Schedule for Fall 2024			
Session	**Dates**	**Topic**	**Assignments**
	Mon, Sep-02	Classes begin on Tuesday of this week; NO LAB	
1	Mon, Sep-09	Check-in, build sample glassware setups	
2	Mon, Sep-16	Simple and Fractional Distillations	
3	Mon, Sep-23	GC of distillation fractions, data analysis in Excel	
4	Mon, Sep-30	Extraction of a mixture, TLC	
	Mon, Oct-07	**No lab - October Break**	
5	Mon, Oct-14	Recrystallize, mp of extraction product	
6	Mon, Oct-21	Computational modeling	
7	Mon, Oct-28	Planning a reaction, ChemDraw	
8	Mon, Nov-04	S_N2 prep of butoxynaphthol	
9	Mon, Nov-11	Acid-catalyzed dehydration and GC analysis	
10	Mon, Nov-18	Kinetics of S_N1 solvolysis (experimental work)	
	Mon, Nov-25	**No lab - Thanksgiving Break**	
11	Mon, Dec-02	Kinetics of S_N1 solvolysis (data analysis)	
12	Mon, Dec-09	Check out	

Additional Outcomes

The use of instrumentation to collect data during experiments is consistently cited by students as a highlight of the 251/252 sequence. Our reexamination of the 251/252 curriculum through this grant has led us to identify access to some workhorse instrumentation (e.g. the gas chromatographs, GCs) as a bottleneck. Based on the outcomes presented here, the working group applied for and obtained funding to purchase two additional gas chromatography instruments (through SERF fund). With the purchase we will have a total of four instruments and will be able to incorporate greater use of the GCs in the redesigned labs. This will grant students even more hands-on experience with the instrumentation and will enhance our ability to incorporate meaningful data collection into the experiments.

Future Development of Chem 251 and 252

Implementation of the redesigned Chem 251 course will need a substantial investment of time and resources. The practical nature of labs means that selected experiments must be modified to work within the Whitman lab schedule (2 hours and 50 minutes, short by national standards). Further, several of the labs will need to be developed from scratch. The incorporation of different instrumentation must also be optimized. The nature of Chem 251 (a service course) requires that everything be essentially "foolproof" since there is little time to make adjustments on the fly while managing large numbers of inexperienced students.

Lastly, the safety concerns associated with work in the organic teaching lab require that each lab be rigorously tested to ensure safe operation by students of varying experience and competency. Our implementation plan will rely on seeking additional PIG funding to power lab development over the summer of 2024. This will most likely involve the work of one faculty member (Collins) and a paid student intern. This would enable us to launch the new labs in fall 2024. In anticipation of this, the department has arranged to have each of the other members of the working group teaching Chem 251 during its first iteration in fall 2024 (Biswas, Juhasz, Götz; Collins will be on sabbatical for the 24-25 academic year).

Further development of the Chem 252 course should be more straightforward now that the learning goals and concept/technique mapping are done. We envision some version of a PIG in 2025 to approach the redesign and implementation of Chem 252. This would equate to three PIG grants spaced over three years for a total redesign of the Chem 251/252 sequence. Given the extraordinary cost of developing these types of labs (e.g., optimizing time/scale of experiments, incorporating instrumentation, purchasing supplies and reagents, writing procedures, etc.) and the large number of students impacted annually (typically over 100 students in seven lab sections), the working group hopes that the committee will look favorably on future PIG applications to finish this work.

Use of Allotted Funds

The working group did not use the funds allotted for refreshments and student assistants ($200 and $320, respectively). Neither seems necessary for the completion of the group's work, as it is reported here.