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# A Combination Course and Lab-Based Approach To Teaching Research Skills to Undergraduates

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Supporting Information

**ABSTRACT:** Undergraduate research is an important capstone experience that provides students with the conceptual and technical aptitude for graduate or industrial research. However, this experience is often compressed into a single term in a course-based undergraduate research experience (CURE) or run by individual faculty members for select students on an ad hoc basis as an undergraduate research experience (URE). One alternative to these two possibilities is to use a team-taught course during students' third year to help them develop fundamental skills that they use to prepare and present a research proposal. This proposal serves as a vehicle for improving students' ability to assimilate information from the primary research literature and for them to practice evaluating the safety and research ethics aspects of projects. Students also use their proposals as research plans for their remaining year and a half of college. Data gathered indicate that this course was effective and that it could be a useful addition to other departments' curricula, particularly at teaching-focused institutions.

| | URE | CURE | CURE/URE |
|---|---|---|---|
| Breadth of Faculty Involvement | ✓ | | ✓ |
| Breadth of Student Involvement | | ✓ | ✓ |
| Depth of Research Experience | ✓ | | ✓ |
| Coverage of Chemical Information | | ✓ | ✓ |

**KEYWORDS:** *Upper-Division Undergraduate, Curriculum, Communication/Writing, Undergraduate Research*

Students can gain many valuable skills by participating in research at the undergraduate level.[1,2] Based on this knowledge and the recommendations from the American Chemical Society Committee for Professional Training (ACS-CPT),[3] the Department of Chemistry and Biochemistry at Mercyhurst University had been requiring all majors to participate in research with a faculty mentor during their final year. The department has 6 full-time faculty members spanning all five subdisciplines of chemistry and typically graduates 3−9 majors per year who go on to attend graduate programs in the natural sciences or health fields. Students in their final year were required to take a one-term research course in which they carried out original research and wrote a thesis describing their findings. While the students who were interested in pursuing a research career often started working on an independent research project long before their final year, many students would put off starting research until their final term. These students often had lackluster theses as the one semester research experience did not provide sufficient time or instruction for students to gain the technical skills and theoretical understanding necessary to carry out and report on an original research project. It became apparent that many of the students who were delaying research either (a) were intending on attending professional school and thus did not see the benefit of participating in research or (b) were not sufficiently motivated or lacked the initiative to become involved in the research process earlier. Upon reflecting on this trend, the faculty decided that the current research model was not providing an adequate experience for many of our majors. In addition, it was difficult for faculty to acculturate students to research and information literacy practices within one term while also training students in the technical and conceptual aspects of their research and helping them to generate usable data. The result was that information literacy skills were often sidelined, and the quality of student theses reflected this. Thus, a push was made to redesign the research curriculum.

In redesigning the research curriculum, several goals were kept in mind. The most important of these goals was to provide students with the following:

- Information literacy skills they would need to successfully search, read, and understand the primary literature.
- Exposure to the safety and ethical considerations necessary for designing and completing a research project.
- An opportunity to propose a research project that was of interest to them and meshed with faculty expertise.
- An opportunity for all chemistry and biochemistry majors to work closely with a faculty member in a research laboratory on an original research project.

Additionally, logistical challenges such as scheduling a time for the course, determining instructors for the course, and

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**Table 1. Advantages of the Research I Course**

| Course Features | Description |
|---|---|
| Team-taught by department | Courseload distributed across several faculty members |
| | Variety of faculty perspectives during class discussions |
| Offered as a J-term course | Students can focus on researching and writing their proposal and gaining technical skills in the laboratory |
| | Faculty can focus on mentoring students and providing intensive support for proposal |
| | Entire student cohort can take the class together, ensuring uniform and quality experience for students |
| Coupled to Research I Lab | Provides a built-in opportunity for faculty to teach students advanced techniques specific to their subdiscipline that may not have been covered other courses |
| Proposal linked to thesis research | Students have time to carry out more in-depth research and gain experience that more closely approximates graduate or professional settings |
| | Students have both interest and a stake in the project to which they are applying their information literacy skills |
| | Course sets students up to carry out more successful senior thesis projects |

determining how to best assess learning needed to be addressed.

The first step in revamping the research experience was to search the existing literature for courses that would help to meet the goals of this redesign. While several reports detailing undergraduate research experiences (UREs) and course-based undergraduate research experiences (CUREs) were found,[4−10] none of the reported examples met all of the specific goals listed above. For example, many of the courses described suffered from limitations such as disproportionate burdens placed on 1−2 faculty who were designated to teach a CURE,[8,10] short durations of research experiences,[4]and the inadvertent exclusions of certain populations of students due to the often competitive nature of UREs.[2,5,9] The linked pair of courses described herein addresses these issues and may prove useful to other institutions in the process of improving their undergraduate research program. Although the program described in this paper was set during our university's January term (a 3 week term before spring semester), we discuss alternative arrangements at the end of this paper.

After considering these findings, as well as the needs of the students attending this institution, it was decided that a combination CURE/URE experience taught during the January term would be most beneficial (Table 1). In order to achieve this combination approach, two new courses Research I and Research I Lab were designed using the elements described above. The Research I class was offered for the first time in 2014 and again in 2015. The Research I Lab was initiated in 2015. Starting in 2015, these courses were taught during the 3 week January term (J-term) by five full-time departmental faculty members. The courses were offered during the J-term to give students the time and space needed to focus on research and proposal writing. Additionally, as students are only permitted to take one course during the J-term, scheduling conflicts for students and faculty were minimized. Students are strongly encouraged to participate in Research I and Research I Lab during their third year of study. Students, especially those who are planning on pursuing graduate studies in chemistry/biochemistry, are also encouraged to use their findings from Research I and Research I Lab as the basis of their senior theses and seminars during their fourth year. The grading format for both courses is a letter grade. The Research I letter grade is based on scores for course assignments and a weighted-average of proposal scores given by the student's three-person committee; each of the students' individual research mentors assign the Research I Lab letter grade.

## ■ RESEARCH I COURSE DESCRIPTION

Research I was designed as the CURE portion of the experience. This course is unique in that it both provides students with relevant background information necessary to complete any research project and focuses the students' efforts toward preparing a proposal for an in-depth research project that could be carried out in their final year. Another unique aspect of the Research I course is that it is team-taught by five full time faculty members. As is true for the students enrolled in the course during the J-term, this is the only course that faculty are involved in, enabling them to attend the class each day even if they are not responsible for lecturing. This allows students to have a more diverse view of science and research as the various faculty members have different backgrounds and are at different stages of their careers. As the five faculty members' expertise spans all subdisciplines of chemistry, students can further see the similarities and differences among these areas.

Research I was a two-credit course taught daily during the J-term. Students were expected to attend and participate in every session of the course. An outline for the course topics and assignments can be found in Table 2.

A final positive aspect of this course is that each student is given the opportunity to work closely with his or her faculty research mentor. Each faculty member is the sole instructor for one section of the one-credit laboratory portion of the course—Research I Lab. The capstone assignment for the course is a research proposal in which each student, with

**Table 2. Course Schedule for Research I**

| Schedule | Topics/Activities |
|---|---|
| Day 1 | Research and the scientific community |
| | Preparing for graduate school, industry, or other options |
| Day 2 | Searching the scientific literature |
| | Electronic library creation and management |
| Day 3 | The classification and objectives of different types of sources |
| | Section content and writing structure of common research articles |
| Day 4 | Reading a primary research article |
| Day 5 | Research practices in analytical chemistry |
| Day 6 | Student presentation on their chosen primary research articles |
| Day 7 | Finding and evaluating information about chemical hazards |
| Day 8 | Research practices in biochemistry |
| Day 9 | Research practices in organic chemistry |
| Day 10 | Research practices in inorganic chemistry |
| Day 11 | Research practices in physical chemistry |
| Day 12 | The peer review process/student peer reviews of proposals |
| Day 13 | Research ethics and responsibilities |
| Day 14 | Student presentations of research proposals |



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guidance from their Research I Lab professor, provides a proposal for a research project that could be carried out during their final year. Work is begun on these proposals during the first week of the J-term, and they are officially presented in both oral and written formats during the final days of the course. This research proposal provides several positive notes to the course including to following:

- A unifying theme and direct application for the information taught in the course.
- A means by which the students can build the background knowledge necessary for carrying out a successful research project.
- An opportunity for students to present scientific information in both oral and written formats.
- The opportunity to engage in research and research-based discussions with their peers and a significant portion of the departmental faculty as part of a small team led by their individual faculty mentor.
- A convenient means for assessing student understanding of research; the assessment of this proposal will be discussed more in-depth later in this paper.

The first section of the course centered on giving students practice with reading and searching the primary literature. It was decided that the course should first focus on the literature so that the students could immediately begin finding papers relating to their research proposal (S04−S05). In addition to learning strategies for reading and parsing primary literature articles, students were also given in-depth information on information retrieval and storage (S07−S08). In one lecture, students were instructed on the use of many popular databases of chemistry and biochemistry literature (Pubmed and the ACS journals were featured prominently, while SciFinder was dealt with in more depth via the faculty research mentors). Students were also instructed on the importance of maintaining electronic libraries and were given a tutorial on how to use Endnote to manage references. Students had to complete several assignments to demonstrate familiarity with reading, searching, and managing the literature (S09−S10). When possible, students were asked to find papers that directly related to the research they were currently working on. This not only gave students an opportunity to expand the references they would use for the proposal but allowed them to see how research scientists use the published literature to inform their own projects.

Students were then required to present a primary article closely associated with their proposed research during the second week of the course. This allowed students to put into practice what they learned about searching, organizing, and reading literature. The significance of the exercise was increased because it represented the first stages of their research proposal development under the mentorship of their faculty research adviser.

During the second part of the course, students were given more in-depth exposure to the traditional subfields of chemistry. This part of the class was particularly informative as the whole course was team-taught by five faculty members. Each faculty member gave a presentation about his or her area of expertise. The presentations varied by faculty member, but most included a brief description of their field, a brief history of their field, a discussion of the types of jobs chemists in their field usually hold, and a discussion of some of the key skills necessary for their field. Each faculty member also required the students to read one or more primary research articles that showcased something specific about their field.

For the final third of the course, students discussed safety and ethics in the laboratory setting. Although students had encountered MSDS information in previous laboratory courses, the safety discussion (S11) used specific example hazards to illustrate relative degrees of risk, specific terms (for example, the difference between short-term exposure limits and time-weighted average exposure amounts for hazardous chemicals), and introduced students to additional sources of safety information such as NIOSH (The National Institute for Occupational Safety and Health) and ECHA (European Chemicals Agency). In addition to learning about safety in lecture, students were also required to write a short paper addressing specific safety concerns that may arise with their individual projects (S12). Students were encouraged to consult their research advisers when completing this assignment. For the ethics section, the course focused on using case studies that would be accessible to undergraduate students (S13). The case studies and discussion questions were mainly designed to call out “gray areas” in ethical reasoning and to help students understand how complicated cases of potential research misconduct can become.

Students continued to draft and refine their research proposals during the second and third portions of the course, with help from their research mentors and from their peers. In particular, each mentor was encouraged to discuss preliminary deadlines with their students to facilitate timely completion of the proposal and adequate time for revision. In addition to faculty guidance, students exchanged draft proposals with each other and provided peer feedback, based on the rubric that would be used for the final evaluation of the documents. On the last day of the course, students submitted their final drafts, delivered presentations on their proposals, and fielded questions. Each written and oral proposal was evaluated by a three-person faculty committee chosen by the student. The committee evaluation was used as both an assessment and a grading tool. If the student planned to continue with their research into their final year, the three-person faculty committee would remain the same for their final undergraduate research defense.

## ■ RESEARCH I LAB COURSE DESCRIPTION

Research I Lab was designed to be the URE component of the experience. All chemistry and biochemistry majors are required to enroll in Research I Lab concurrent with Research I. This mandate ensures that all students have the opportunity to work in a research laboratory and bypasses the concerns of traditional, competitive UREs. All five of the faculty members who are involved in teaching Research I are also available for mentoring students in Research I Lab. Research I Lab is a one-credit course. Students are expected to perform laboratory work on a daily basis during the J-term that they are enrolled in this course.

By the spring of their second year, students are required to choose a research mentor. This process is facilitated by a formal process of student/faculty interviews during students’ first year. This is a relatively early selection, but our experience has been that formal support from a faculty member at this stage is very useful, and students whose interests change are generally permitted to change mentors, as well. Students are welcome to ask to work with any of the participating professors (pending professor approval) and have an option to work on projects



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from all subdisciplines of chemistry. As our department is rather small (3−9 majors/year and 6 full-time faculty members), each student is able to find a willing faculty and no single faculty member feels overburdened with students. Thus, students and faculty are able to work closely together to provide optimum mentorship for a research experience. During the J-term course, students work with their faculty mentor to gain the necessary manual skills to carry out their research project. Specific attention is paid to teaching students advanced techniques that they likely have not encountered in their previous laboratory work (such as Schlenk technique, advanced instrumentation, setting up biological assays, etc.). While some students have started their research project in their first or second year, it is expected that many students will be entering the research lab for the first time. The student is able to work closely with the faculty member for several hours each day to learn proper techniques and to begin gathering data related to their proposed project. As Research I and Research I Lab are taught concurrently, students are simultaneously exposed to the whole process of planning and conducting research.

The Research I Lab is seen as an introduction to specialized research techniques, and it was not formally assessed. Students were, however, assigned letter grades based on criteria established by individual faculty mentors.

## ■ ASSESSMENT

Research I Lab was designed to be the URE component of the experience. All chemistry and biochemistry majors are required to enroll in Research I Lab concurrent with Research I. Research I and Research I Lab were designed as introductory research experiences. It was, therefore, deemed appropriate to assess students on their ability to plan for research rather than on the outcomes of their completed projects. The proposals that the students wrote as part of Research I were formally assessed using a faculty-designed rubric (S02). In addition to their mentor for Research I, each student was required to choose two additional faculty members to serve as a committee. While most students chose faculty from within the department, students working on interdisciplinary projects were allowed to select faculty members in other departments (pending faculty willingness). Each student was evaluated by each of the three committee members and assigned a letter grade at the completion of Research I.

Overall, students were very successful in writing their proposals. The average score for students on the entire assignment was a 13/15 ($n$ = 6). Individual rubric areas were also assessed, and students also generally did well in each of these areas (Figure 1). Students were most proficient at finding appropriate references and at linking the background information they gathered to the hypothesis that they proposed to test (means = 2.8 and 2.9 out of 3, respectively). This indicates that the in-depth work done in the first week of the course on searching and reading the literature is effective at facilitating student development of information literacy skills. Students were generally weakest when it came to providing a thorough proposal (mean = 2.2 out of 3). This is not surprising given that this aspect of the assignment builds on the others, requiring the student to synthesize their prior research into a research plan. Although data cannot be directly compared to earlier courses, the faculty involved agreed that proposals improved significantly over previous years, particularly when the relative academic ability of the students involved was taken into account.

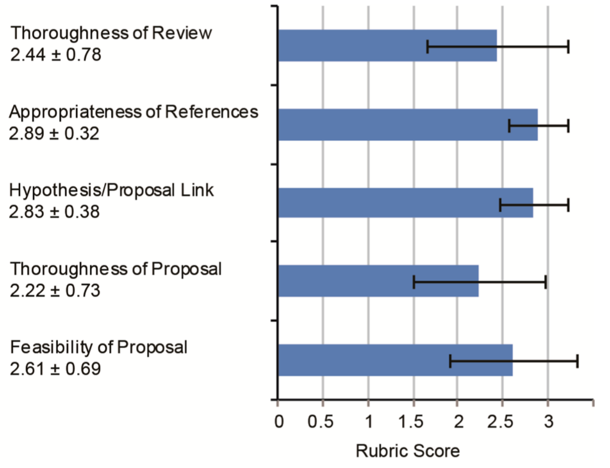


**Figure 1.** Assessment data for the student proposals from Research I. Bars represent the average score from each committee member for each student (18 total reviews represented for 6 students). Each dimension was scored on a scale ranging from 0 (absent) to 3 (excellent). Error bars indicate the standard deviation. These data are for the J-term course that was run in 2015.

## ■ A BROADER RESEARCH EXPERIENCE

Not all students plan on pursuing a research-based career. It is necessary, however, for all students majoring in chemistry or biochemistry to understand what is involved in chemical research and what it is like to work in a research setting. For students who are interested in pursuing additional undergraduate research, the Research I and Research I Lab provide a strong launching point from which they can start further investigations. Students already have much of the background knowledge and technical skills necessary to start a project. Students who want to pursue further research have three full terms available to do so (Spring of their third year and Fall and Spring of their fourth year). It has been noted that "In many UREs it takes over a year for students to gain sufficient understanding to make sense of the science practices or concepts in the lab."[2] By requiring students to start their research by the J-term of their third year, the department is providing ample time for interested students to develop the skills needed to fully understand their research projects. Students are not required to continue research past their third year, and preprofessional students may opt not to keep up with their projects. By virtue of completing Research I and Research I Lab, these students will have at least been exposed to the research process and will obtain a well-rounded chemical education.

Two out of three students who took Research I in 2014 decided to go on with research and have used their Research I proposal as the basis of their senior theses. Five out of six students who took Research I in 2015 are planning on continuing their project into their final year.

## ■ CONCLUSIONS AND FUTURE DIRECTIONS

In our experience, this combined course- and lab-based approach to teaching undergraduate research has been very successful and has many unique benefits. First, by offering this experience during the J-term, students and faculty can focus on both the technical and conceptual aspects of research without competing for time with other courses or activities. This also allows the class to be team-taught by five faculty members. The


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team-teaching aspect both broadens the content of the course as well as reduces the burden that one single faculty member is expected to carry. Also, faculty mentors can spend extensive one-on-one time instructing their students in hands-on laboratory techniques. Second, since the students are doing the course and research components at the same time, the two experiences can be mutually informative. This ensures that all students get both the theoretical and practical understanding of how to conduct research projects. As both parts of the experience are mandatory, all students are able to get hands-on research experience. This helps to mitigate biases that may occur in traditional undergraduate research arrangements, where students are chosen for research based on applications. Third, the students are required to take this course in the J-term of their third year. This means that students have three full semesters (and possibly a summer) to work on the projects that they propose. Students can have a more in-depth research experience and use their proposal to launch a full research project. Based on the assessment data gathered for student proposals, students are able to use this combined experience to write a successful research proposal. Also, based on informal conversations with students and on the high number of students who plan to continue their research into their final year, it can be concluded that this combined approach offers a valuable introduction to research.

This model has been successful at our institution, and we believe it would likely also be successful at other smaller, teaching-focused institutions, as well. Although our department is relatively small, the classroom activities for Chemistry 410 should scale to larger groups of students with minimal difficulty. For departments where it is impractical to have all majors involved in research for long periods of time, this course may provide a useful screening tool for determining which students have the desire and the aptitude to make the most of the research experience. We recognize that many institutions do not have a J-term, and there are several possible modifications that could be made as part of adapting this curriculum. The course lends itself well to being taught during a "mini-session" (in which two half-terms of 6−8 weeks are nested inside a traditional semester)—in this case, each week would cover approximately 2 days worth of material from Table 2. Expansion to longer sessions, either 10 week quarters or 15 week semesters, is possible, as well, although scheduling conflicts for both students and faculty may hinder the intense discussion and feedback sessions that were facilitated by having multiple faculty members present with the students. The very first iteration of Chemistry 410 was taught during a 14 week spring term, meeting each week for a single hour of classroom time to cover material equivalent to 1 day from Table 2. It has been the authors' experience that students tend to write better proposals when they can focus exclusively on the Chemistry 410/412 courses, but given sufficient faculty support, it is entirely possible for students to write reasonable proposals during a partial or full term. If it became necessary to drop portions of the course, the "research practices" material (days 5 and 8−11 in Table 2) could be compressed or taught as part of the corresponding upper division coursework. If the material described in this paper was to be used as the basis for a semester-long course that met for 3 h per week, one option would be to combine the lecture and lab portions into a single course that is listed and taught as a lab. Students might attend short classroom discussions, followed by time dedicated to mentored research or work on their proposals. In principle, additional classroom time could be spent discussing resources in more detail, but in the authors' experiences, there is a point of rapidly diminishing returns for these classroom discussions, beyond which it is much more useful for students to get help as problems or questions occur during research. In any of these cases, we believe that the information contained in this paper and its Supporting Information will prove extremely useful as a starting point for similar courses.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00390.

> Copies of course material for Research I, including a course syllabus, rubric for the proposal, faculty presentations, activities, and student assignments (PDF)

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### Notes

The authors declare no competing financial interest.

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