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A Model for an Introductory Undergraduate Research Experience

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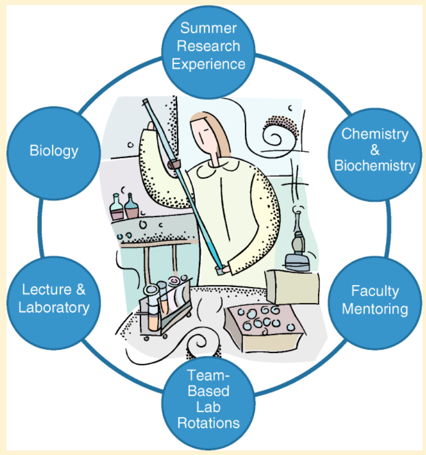
S Supporting Information

ABSTRACT: An introductory, multidisciplinary lecture−laboratory course linked with a summer research experience has been established to provide undergraduate biology and chemistry majors with the skills needed to be successful in the research laboratory. This three-credit hour course was focused on laboratory skills and was designed to reinforce and develop the students' laboratory techniques and problem-solving skills, as well as to give encouragement to participate in a summer research project. This skills course consisted of a lecture section with team-based laboratory rotations of five-weeks each. Most students in the rotations had the opportunity to work in both biology and chemistry laboratories. The skills course culminated in several students being chosen to continue research in the summer with a research stipend while under the direction of one of the faculty mentors. The summer research projects were all collaborative efforts between chemists and biologists. Data are provided from voluntary entrance and exit student surveys to determine students' overall skill levels and interests before and after completion of the skills course. This course was valuable in encouraging students to become involved in and committed to research, for teaching them laboratory techniques, and for helping them evolve into independent researchers.



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KEYWORDS: *Second-Year Undergraduate, Upper-Division Undergraduate, Curriculum, Interdisciplinary/Multidisciplinary, Inquiry Based/Discovery Learning, Ethics, Professional Development, Undergraduate Research*

Faculty from the Department of Biology and the Department of Chemistry and Biochemistry at the University of Colorado Colorado Springs (UCCS) have designed and implemented a lecture−laboratory course coupled with a summer research program to attract, train, and retain undergraduates in chemical and biological research. The benefits of undergraduate research are many and well documented.[1−6] The American Chemical Society (ACS) Committee on Professional Training (CPT) has identified undergraduate research as an important element of an undergraduate curriculum, providing benefits to students, faculty, and the degree program.[7,8] There can be significant barriers to productive undergraduate research.[9−11] At UCCS, participating faculty perceive the following barriers to be the most critical: involving students in research earlier in their career and providing opportunities to work during the summer without distractions.[9] An important aspect of this program is that students realize they do not have to wait until their last year to pursue research. The traditional model of undergraduate research has students completing most or all core courses prior to doing research,[12] though others have suggested earlier involvement may be beneficial.[9,13−16] This program encourages earlier involvement in research and it is hoped that by so doing, it has an impact on student's career choices while they are still in the midst of completing core courses. This model incorporated summer research stipends, which allowed many students to focus solely on research, without distractions from classes and jobs. The objectives of the course were to:

- Increase student interest in research and encourage students to join a research program
- Involve students in research early in their academic careers
- Create stronger collaborative ties between the Department of Biology and the Department of Chemistry and Biochemistry
- Give students the skills, laboratory techniques, and problem-solving methods to help them be productive in a research setting
- Keep students abreast of safety issues and precautions when working in the laboratory
- Create an environment for students to work and learn as part of a team
- Strengthen faculty−student and student−student communication
- Help students consider the ethical consequences of research
- Introduce students to a variety of techniques not commonly taught in traditional laboratory classes until upper-level courses
- Enable students to ably apply skills learned in the course to their summer research experience

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- Enable summer research students to be active contributors to new scientific developments
- Provide opportunities for students to search the scientific literature and effectively communicate scientifically

The work described here summarizes our efforts to achieve these outcomes and assess the effectiveness of the strategies employed throughout the course. Pre- and postclass surveys, along with end-of-summer surveys for students that participated in summer research projects, were used to help assess the experience. Although other research courses have been reported,[11,17−19] the course described here is unique because it gives undergraduate students an opportunity to rotate through more than one laboratory (students rotate through both biology and chemistry laboratories); students work closely in the laboratory with the professor, rather than with a teaching assistant, graduate student, or separate laboratory instructor, and the laboratory experience is coupled with a weekly lecture−discussion experience that gives students opportunities to communicate scientifically.

Six faculty members from the two departments recruited 16 second- and third-year undergraduate students to participate. Although first-semester organic chemistry was a prerequisite, most students take that course during the fall semester of their second year, and nine of the 16 were second-year students. These students registered for a required three credit hour lecture−laboratory research course in the spring semester of 2010 and met once per week for the lecture portion of the course. They were divided into teams of two to four students and paired with one of the participating faculty members for the laboratory portion of the course. Faculty mentors tried to engage each member of the team so that no single student did most of the work. Lab rotations consisted of three, five-week blocks. Thirteen of the students rotated through three different faculty member's laboratories, one student rotated through two laboratories, and two students remained in the same laboratory due to scheduling difficulties. Most students had the opportunity to work in one biology laboratory and two chemistry laboratories. Near the end of the semester, eight students were selected to continue their research with one of the participating faculty with a stipend funded by the Merck/AAAS Undergraduate Science Research Program.

It is not feasible to require undergraduate research as part of the degree program at a large university. The high student-to-faculty ratio makes it impossible to support all of these students in a research project.[20] This research skills course provides a way for faculty members to recruit outstanding students earlier in their career and to develop collaborative projects between the departments and gives students an opportunity to perform research and to familiarize themselves with the research happening on campus. Anecdotally, prior to this course, the faculty who teach only upper-level courses often had difficulty recruiting beginning students and found that having students for just the two semesters prior to graduation was not always effective.

■ COURSE ORGANIZATION

Faculty Commitment

The skills course is taught once per year, in the spring semester. Each of the faculty trained students in his or her research techniques for the laboratory portion of the course. In some cases, faculty taught the lab as an unpaid overload. Five of the six faculty had three groups of students rotate through their laboratories during the semester, while the other faculty member had just one group. One of the six faculty members was responsible for the lecture portion of the course, but all faculty were invited to give an oral presentation related to their research during a lecture.[21] Responsibility for the lecture portion of the course rotates among the participating faculty members.

Recruitment of Students

To create student interest, an external speaker was invited to give a luncheon research talk discussing the multidisciplinary nature of modern biology and chemistry research. Interested students could download an application packet from the Department of Chemistry and Biochemistry home page. The packet included a description of each faculty member's area of research. Students ranked their top three choices of projects and were required to write a one-page essay describing why they wanted to do research and how participation in this course fit with their career plans. Enrollment was originally limited to 12 second- and third-year students, but there were twice as many applicants as spots, so enrollment was increased to 16.

Lecture

The lecture−laboratory course included a weekly 75-min lecture, in which several of the participating faculty presented topics crucial for conducting undergraduate research. These topics included research skills such as literature searching, keeping a research notebook, and consideration of ethical issues. For most students, this is their first exposure to these skills.

Near the beginning of the semester, each student chose a recent (within the last five years) research article of interest to him or her. As the semester progressed, students gave both oral and poster[22] presentations describing the data in their chosen article. Examples of papers chosen by the students, as well as the rubrics used to assess their presentations, are included in the Supporting Information. The class was split into two groups, with students self-assigning to one of the groups. The first group of eight students gave oral presentations in week seven and poster presentations in week 13. The second group of eight students gave oral presentations in week eight and poster presentations in week 14. Participating faculty members filled the remainder of the class meetings by presenting their research to the students, thereby allowing students that did not have the opportunity to rotate through their laboratory the opportunity to learn about their research. The course schedule is shown in Table 1.

The research skills course gives students a valuable opportunity to practice scientific oral communications before their senior seminar, a required capstone course that gives final year students an opportunity to present and discuss scientific literature. Poster preparation and presentation and searching and reviewing literature are skills unique to the research skills course. The poster presentation on a literature article guarantees that each student will experience presenting a poster. However, presentation of posters on students' own work is strongly encouraged. Three groups of students in this course also presented posters at the local college consortium conference at the end of the spring semester based on the work done during one of their rotations.

Laboratory Block Activities

Students attended at least 6 h of laboratory each week in three different five-week blocks. The topic areas of research were assigned based on student interest and student and faculty schedules. Each five-week block was designed to allow students

Table 1. Weekly Schedule for the Lecture Section of the Research Skills Course

Week	Description	Assignment Due
1	Syllabus and schedule	None
2	Use of scientific databases	Use of SciFinder Scholar
3	Keeping a proper laboratory notebook	—
4	Reading scientific literature and writing scientific documents	Read handouts
5	Making scientific presentations	Rotation 1 lab notebook
6	Making ethical decisions	Read case studies
7	First group, student oral presentations	Select article for Poster presentation
8	Second group, student oral presentations	Select article for Poster presentation
	Spring break	—
9	Faculty research presentation, bioinorganic	—
10	Faculty research presentation, organic	Rotation 2 lab notebook
11	Faculty research presentation, analytical	—
12	Faculty research presentation, health sciences	—
13	First group, student poster session	Poster presentation based on article
14	Second group, student poster session	Poster presentation based on article
15	No meeting	Rotation 3 lab notebook, journals

to learn (1) the methodology of a specific research area, (2) how to understand and interpret journal articles of importance for each area, and (3) methodology of instrumentation in chemistry and biology laboratories. At the end of each block, students submitted a copy of their notebook and a brief report. Students were expected to keep journals with at least weekly entries detailing their experiences in the lecture and laboratory. Student guidelines for assignments, as well as learning goals for each rotation, are provided in the Supporting Information. Relevant student comments from the journals are included with the descriptions and are given in italics.

Summer Research

The summer component extended the laboratory skills and associated competencies into an eight-week research program; students were paid a stipend as an incentive. These factors encouraged students to focus on research and gave them the opportunity to contribute novel results to the scientific community. Faculty collectively selected eight of the participating students to conduct summer research for 30 h a week for eight weeks. The stipend allowed students who would otherwise be employed in other areas off campus to be exposed to a laboratory research employment situation. Students who were not selected for summer stipends were invited to conduct summer research under an independent study (research course) in chemistry or biology. Eleven of the 16 students who started the lecture–laboratory course continued to conduct research beyond this program in later semesters.

Students participated in one of two main projects that were collaborative between faculty members in the Department of Biology and the Department of Chemistry and Biochemistry. The first project involved faculty specializing in molecular biology, immunology, bioinorganic, organic, and biophysical chemistry. The goal was to gain a deeper understanding of ligand binding to hexokinase (HK) isozymes. The second collaborative project emphasized exercise physiology and analytical chemistry to gain a clearer understanding of the neurological mechanisms regulating cerebral blood flow. More details on these projects are included in the Supporting Information.

■ ASSESSMENT

Grading

Attendance and participation grades were recorded for the lecture portion of the course and for each laboratory rotation. No examinations were given in lecture or laboratory. In the lecture portion, students accrued points from both oral and poster presentations. At the midpoint of the semester, students gave a 5–10-min oral presentation covering a scientific literature article chosen by the students and approved by the supervising professor. This oral presentation was further developed into a poster presentation, which served as the final assignment for the lecture portion of the course. Faculty assessed both presentations and assigned points based on the time limit, structure of the presentation, use of visual aids, layout, and delivery of presentation (see Supporting Information, section "Grading Rubrics," for the full grading rubrics). At the end of each laboratory rotation, students submitted a copy of their notebook pages with detailed data interpretation in the format of a short report. These were assessed for format, experimental procedure, results and calculations, discussion and conclusions, and references (also in the "Grading Rubrics" section of Supporting Information). Grades were based on total points acquired, and grades were assigned on a typical 90, 80, 70, 60 scale. All of the students in the course received a final A grade. High levels of success were expected, as the application process gave preference to students with demonstrated academic proficiency.

Evaluation of the Skills Course by Students

Students in the skills course provided feedback through entrance and exit surveys, student journals, and faculty course questionnaires (FCQs). Students participating in the summer stipend program also completed a survey. The answers to questions were either yes or no; open-ended; or very unsure, unsure, moderate, confident, very confident. Students' exposure to laboratory skills and associated laboratory techniques, along with their confidence levels and professor interactions, was analyzed by comparison of the entrance and exit surveys. Thirteen students completed the entrance survey and 14 completed the exit survey. One important goal of the skills course was to introduce students to laboratory techniques earlier in their careers, and the surveys were used to assess students' exposure to and comfort level with many of the techniques. Figure 1 shows 10 of the laboratory techniques students addressed in the survey. Students responded yes or no when asked if they had ever performed the experimental technique mentioned. Collectively, students reported increased exposure to these skills, with the greatest improvement in air-sensitive methods, which are not included in most undergraduate curricula, at least not in the first or second years. The skills to which students were exposed varied depending upon the rotations in which they participated and explains why 100% was frequently not achieved. Students also indicated they had increased experience in scientific communication skills, literature-research skills, and consideration of ethics, as shown in Figure 2. Again, students responded yes or no when asked if they had ever performed the research-related skill mentioned. A marked increase was observed for oral and poster presentations, using SciFinder Scholar, and critiquing a literature article. The complete survey, including responses, can be found in Supporting Information.

Students rated their confidence level in several areas of research methodology central to the goals of this course using a

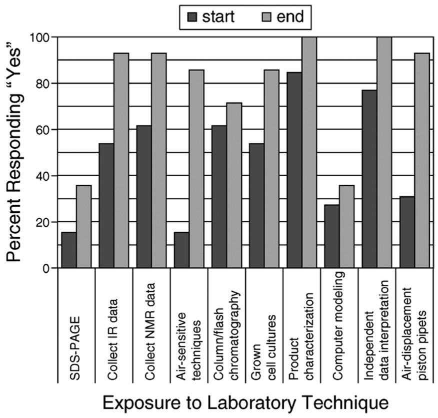

Figure 1. Student responses to the survey question asking if they had ever performed the experimental technique.

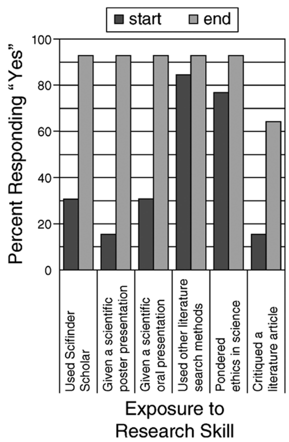

Figure 2. Student responses to the survey questions asking if they had ever performed the research-related skill.

5 point Likert scale (very unsure to very confident) at entrance and exit. The areas of greatest improvement in "very confident" levels are shown in Figure 3; all of the areas surveyed are shown

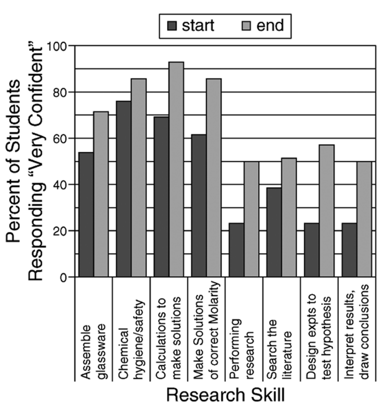

Figure 3. Student responses to the survey questions asking if they felt very confident in the listed areas of research methodology.

in the Supporting Information. Nearly all of the categories shown had 100% of students reporting "confident" or "very confident". Of particular note is that 100% of students reported being confident or very confident "in keeping myself safe from accidents and chemicals" in the laboratory and the number of students that felt very confident designing experiments to test a hypothesis more than doubled. A comment from a student journal reads, "*This was a great class to familiarize students with laboratory and research procedures. Exposure to the research science field experienced in the class is unrivaled...*"

Entrance and exit survey results also showed increased interaction with professors. On the weekly level, the likelihood that students would visit a professor's office increased from 30.8% to 85.7%, make an appointment to see a professor increased from 7.7% to 42.9%, and e-mail a professor with a question increased from 38.5% to 78.6%. A comment from a student journal highlights this sentiment, "*This class helped me gain the confidence to talk with my professor and other students in my class. I am now encouraged to continue participating in undergraduate research as well as talk to my professors in order to have understanding of the subject in which they teach.*"

Although the student comments in surveys and journals were overwhelmingly positive, there were some suggestions for improvement. The surveys were given anonymously, but the journals were not. Some students expressed frustration with the scheduling and felt that five-week rotations were too short. Others requested that the course be taught over two semesters or that the number of rotations be reduced from three to two.

Assessment of this course was also done using a faculty course questionnaire (FCQ). The FCQ is a standardized questionnaire administered by the university upon completion of a course. The summarized FCQ results can be found in the Supporting Information. The most notable result of the survey was that students estimated the average time spent on the course as 10−12 h per week. This was significantly more than the required hours per week, which included 6 h of laboratory time and 75 min of lecture. The additional time may have come from preparation time for presentations, journal searches, and in some cases more time to conduct extra laboratory experiments. Another interesting point from the FCQ results is that students felt they learned significantly more in this course than other courses in the departments, the College of Letters, Arts, and Sciences, and the University overall.

Evaluation of the Summer Research Experience by Students

The student summer survey consisted of two open-ended questions and one that asked students to rate the value of the summer research experience. Six of the eight students responded. All of the students reported it was a valuable experience, with five reporting it as exceeding expectations, and one reporting it as having met expectations. Some of the responses to the open-ended question, "Did this research experience change or influence the course of your education?" were:

> *"The research experience further pushed the option of applying to a Ph.D. program. It did lead me to participate in research during the regular fall semester."*

> *"This course reinforced my enthusiasm for research and expanded the type of research I have been exposed to. The extra exposure helped give me perspective on the types of research available and how interdisciplinary research can provide interesting and profound results."*

The second open-ended question was, "What are some of the personal gains you achieved as a result of this research experience?" Some comments were:

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"It made me realize that research is a possibility in my future. It provided an introduction to what research actually is."

"I have learned many new laboratory techniques and also have gained a great deal of knowledge about synthetic chemistry which has proved very useful in many areas."

"We have achieved further progress into our multi-step synthesis... We were able to go to a regional ACS meeting to present our research data, which was a great experience."

Evaluation of the Course by Instructors

The participating faculty members were surveyed regarding his or her experience in the course. More detailed responses to survey questions are given in the Supporting Information. Five faculty responded (one faculty member left the University during the course). Four of the five respondents agreed the course improved their relationship with the students; the fifth was neutral. Faculty disagreed about student preparation; two asserted that selected students were strongly prepared, two asserted they were poorly prepared, and one asserted they were moderately prepared. However, all five faculty members agreed that the students displayed great improvement over the course of the semester, and all five agreed to allow the students they had in their rotations to continue working in their laboratories after the semester ended. When asked, "Would you recommend participation in this course to other instructors in order to introduce their area of research to possible research students?" all five agreed or strongly agreed with the statement. This course was very time intensive for the instructors. One faculty member estimated spending 13−15 h per week on this course, two estimated 7−9 h, and one estimated 4−6 h (one skipped the question). This sentiment was echoed in discussions among the participating faculty.

■ IMPLEMENTATION DETAILS

The UCCS College of Letters, Arts and Sciences provided $10,000 in matching funds, and each of the participating departments contributed an additional $5,000 in matching funds to be spent during the first three years of this course. $11,000 was equally divided over three years for reagents and small equipment throughout the semester-long course. These funds were equally divided among participating faculty members. The remaining $9,000 was spent as follows: $2,000 per year was allocated to support students presenting at a regional or national meeting, $700 per year was allocated to a visiting scientist lecture series to cover the speakers' travel, and $300 was allocated to host an on-campus research symposium. This symposium was held in the fall in conjunction with the visiting scientist lecture and used as a tool to recruit students for the following spring course. The funding from the Merck/AAAS Undergraduate Science Research Program was used solely for summer activities and included funds for student stipends as well as consumables used in the research. No faculty stipends were paid. More implementation details can be found in Supporting Information.

■ DISCUSSION

Program Strengths

The lecture part of the course emphasized important research topics: literature searches, keeping a laboratory notebook, consideration of ethics issues, and scientific communication. These activities were supportive of two goals of the skills course (provide opportunities for students to search the literature and communicate effectively and help students consider ethical issues). The laboratory part introduced students to a variety of techniques not often taught in traditional first- and second-year laboratories, as well as how to keep themselves safe in a chemical setting. These activities were supportive of two of the goals for the skills course (keep students abreast of safety issues, and involve students earlier).

The team approach benefited the students by helping them learn from each other and discuss difficulties. Working as a team provided a positive peer pressure for students to show up to the lab on time, to actively participate in the project, and when experiments did not work as planned, provided a source of moral support. These activities worked toward the goals of creating an environment for students to work and learn as part of a team and strengthening student−student communication.

Providing feedback and incentives affects student motivation[23] and is an important part of the program. Some teams received feedback on their work through poster presentations on their projects at a local undergraduate research symposium, in addition to the feedback received in the classroom and laboratory settings. Many students who earned a stipend for summer research have continued their research beyond that summer period, and seven students have given presentations at national or regional scientific meetings. These activities worked toward the goals of increasing student interest in research, encouraging students to join a research program, helping students be productive in a research setting, providing opportunities for students to search the scientific literature and effectively communicate scientifically, having students apply skills learned in the skills course to their summer research experience, and enabling summer research students to be active contributors to new scientific developments.

An important aspect of this program is that students do not have to wait until their final year to pursue research. This program encourages earlier involvement in research. Ideally, completing our skills course should prepare students for an undergraduate research experience. A summer research experience "...can be one of the most profound experiences of their college education"[24] and preparing students for undergraduate research is viewed by faculty mentors as a crucial step for students to become involved in undergraduate research.[25,26] After taking the skills course, eight of the 16 students proceeded into the summer projects, and some continued into their later college years. An additional three of the students from the course continued research in a group during later semesters of their college careers. Of the 16 students in the program, approximately half have remained in close contact with some or all of the participating faculty members (supporting the goal to strengthen faculty−student interactions, at least in the short term). At present, seven plan to attend graduate school, eight plan to attend a professional school, and one plans to pursue an M.D.−Ph.D.

Apart from the goals stated in the introduction, other unexpected benefits of the program were found. Junior faculty found this program to be particularly helpful because at the start of their research careers it is often difficult to recruit the best, most dedicated students. In the authors' experiences, students more often approach faculty that have been at the University longer to do research with them, perhaps because their research is more well-known within the department or they may have recommendations from other students that have been or are in that research group. The selection process for the class ensured that bright, talented students would be accepted into the program and the rotations ensured that several of the students would become familiar with the junior faculty's research. Anecdotally, students who continued on a research project into the summer or fall also seemed to be better prepared to begin an independent research project than students that did not participate in the course. In addition, the rotations exposed students to research in both biology and chemistry and they could observe the multidisciplinary nature of the projects.

Potential Improvements

Two of the stated goals, developing stronger collaborative ties between departments and helping students consider the ethical consequences of research, are difficult to quantify. Although additional collaborative projects have begun between the departments, it cannot be ascertained definitively that these new collaborations are a result of this program. Likewise, it is difficult to know if students weighed any ethical dilemmas.

Scheduling students and faculty to work together in the laboratory was difficult at times as students were of differing years and therefore taking different courses. A majority of our students also work part-time, and each student had a different work schedule as well. Likewise, each faculty member had a different teaching and research schedule. As a result, the time that students and faculty were available changed with each rotation because a different group of students would enter the laboratory every few weeks and would have to match their schedules with the schedule of the faculty member. In addition, the short duration of the rotations (five weeks) gave insufficient time to achieve some rotation learning goals (see the Supporting Information). Decreasing the number of rotations from three to two and limiting entrance to the course to students taking only 15 credit hours or less may help achieve more of the learning goals and alleviate some of the scheduling difficulties.

When compared to the usual undergraduate experience pathway, students in the skills course were exposed to more skills earlier in their career than in the traditional path. Some of the rotations had students performing novel research (e.g., organic synthesis), but other rotations did not (e.g., the bioinorganic rotation used a well-documented synthesis to teach air sensitive techniques). Perhaps learning a mixture of basic skills along with some research progress in each group may be a solution. Allowing students to spend more time on a project with one less rotation may allow them to make more significant research progress. Lastly, finding extended funding for students to enable summer research experiences may prove difficult, losing an important incentive of the skills course.

■ CONCLUSIONS

Students enrolled in the skills course and summer research program registered a high degree of satisfaction with their experience as indicated in the student entrance and exit surveys, FCQs, and student journals. Roughly half of the students that participated in the program have presented their research at ACS regional or national meetings. Although weaknesses in the course design were found, some will be addressed in subsequent semesters, and the overall experience was extremely positive for both students and faculty. Including all participating faculty, 11 of 16 trained students from this course continued participation in biological and chemical undergraduate research in later semesters.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Examples of papers chosen by the students; the rubrics used to assess student presentations; student guidelines for assignments; learning goals for each rotation; details on lab projects; survey questions and responses; summarized FCQ results; implementation details. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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