SPRING 2010 FACULTY ACCREDITATION REPORT—CHEMICAL SCIENCES

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UPDATES SINCE JANUARY 2009 REPORT

This report revises and updates the original Chemical Sciences report submitted in January 2009. The principal changes are the addition of a minor in Chemical Sciences and significant revisions in our approaches to assessing our Program Learning Outcomes in fundamental knowledge, communication, and ethics. We are also introducing a new required course to insure that our majors receive appropriate instruction in scientific communication and in ethics.

I. PROGRAM DESCRIPTION

Chemistry is often known as "the central science" because of the key position it occupies in modern science and engineering. Most phenomena in the biological and earth sciences can be described in terms of the chemical and physical behavior of atoms and molecules, and chemical principles also underlie much progress in medicine and engineering. In addition, chemical systems are fascinating and often beautiful in their own right. Recent developments in the chemical sciences are increasingly directed toward the study of phenomena at the nanoscale, the size range intermediate between individual molecules and macroscopic matter. The ability to measure, understand, and control the properties of matter on these size scales allows us to draw conceptual and practical connections between the submicroscopic world of atoms and molecules and the macroscopic world with which we interact.

UC Merced offers an undergraduate major leading to a B.S. degree in the Chemical Sciences. All of our programs are designed to meet the requirements for approval by the American Chemical Society. Students who complete an approved curriculum may obtain a certified degree, a valuable credential which serves as national-level recognition for successfully completing a rigorous academic chemistry curriculum in an ACS-approved department.[1] The curriculum is designed to meet the needs of students who plan to end their formal education with a bachelor's degree as well as those who wish to go on for an advanced degree. The UC Merced chemistry B.S. graduate is well prepared to pursue a career in chemistry or an allied field. A degree in the chemical sciences opens the door to a wide variety of careers in industry or government service, forensic chemistry in crime laboratories, commercial fields such as patent law and scientific writing, and high school science teaching. Many chemistry majors go on to

graduate study to prepare for careers in teaching and/or research at the college or university level, or research positions in the chemical, pharmaceutical, electronics or other high-tech industries. A major in chemistry is also an excellent foundation for medical school or other careers in the health sciences.

We offer both a basic chemistry program and emphasis tracks in biological chemistry, environmental chemistry, and materials chemistry, which allow students to pursue interdisciplinary areas within a degree program that is still focused on chemistry. Many aspects of our program are fairly standard among chemistry programs nationwide. Our students take foundational courses in math (through linear algebra and differential equations), physics (two semesters) and biology (one semester) in addition to the School of Natural Sciences requirements in general education, a computer science course, and a probability and statistics course. Required chemistry courses include a year of general chemistry with lab, a year of organic chemistry with lab, a year of physical chemistry, one semester each of instrumental analysis, inorganic chemistry, and biochemistry, and a combined physical chemistry and instrumental analysis lab. Further upper-division courses may be selected from a range of electives in chemistry, biology, earth systems science, materials science, and engineering depending on the emphasis track chosen. Mirroring the flavor of our institution as a whole, the UC Merced Chemical Sciences program is considerably more interdisciplinary than are most chemistry programs in allowing more of its upper-division course requirements to be met through chemistry-based courses offered in other disciplines. This breadth also permits us to offer both undergraduate and graduate programs in chemistry with a faculty that is currently far smaller than that of most chemistry departments at research universities.

Research is a very important part of the Chemical Sciences major at UC Merced. All of our majors are required to complete at least 2-4 units of CHEM 95 or CHEM 195, lower-division or upper-division undergraduate research. (The minimum requirement varies with emphasis track because of the different amounts of formal laboratory coursework required for the different tracks.) Thus far the number of chemistry majors has been sufficiently small that we have been able to provide research opportunities for all chemistry undergraduates who want them, as well as for some students majoring in biology and other fields who sometimes switch to chemistry after getting experience in a research laboratory. However, as of the middle of Spring 2010 there were 94 declared CHEM majors. Should most of these students remain in the major, seven chemistry faculty will not be able to accommodate all of them and we will need to revisit this requirement.

A minor in Chemical Sciences was approved in Spring 2010. Course requirements for the minor are two semesters of general chemistry, two semesters of organic chemistry, and three additional upper-division chemistry courses. As of Spring 2010 only one student had declared the CHEM minor. We expect that there will eventually be more, but because of the perceived difficulty of upper-division chemistry courses it is unlikely that this will ever be a highly popular minor.

[1]ACS will not consider a chemistry program for approval until it has been accredited by its regional accrediting body (WASC in our case) and has awarded an average of at least two degrees annually over a five-year period. As our first four majors graduated in Spring 2009, the earliest date at which ACS approval is possible would be 2014.

II. ASSESSMENT PLAN

A. Timeline and goals

The Chemical Sciences faculty has defined a set of program learning outcomes listed in Part B. Assessment of these outcomes is being phased in on an annual basis as outlined below:

Outcome	*Initiate collection of evidence*	*Evaluate evidence*	*Initiate response*
1. Fundamental knowledge and skills	spring / summer 2009	summer / fall 2009	fall 2010
2. Scientific methodology	fall 2009 / spring / summer 2010	summer / fall 2010	fall 2011
3. Communication and teamwork skills	fall 2010 / spring / summer 2011	summer / fall 2011	fall 2012
4. Citizenship, ethics, role of chemistry in society	summer 2012	summer / fall 2012	fall 2013

Evidence concerning Outcome 1 was collected at the end of spring semester and the beginning of summer of 2009 and was evaluated during summer and fall of 2009. The chemistry faculty met during fall semester to discuss what had been learned. Our conclusions were summarized in the Assessment Report submitted in January 2010. We found that the protocols we had initially adopted for assessing Outcome 1 did not provide the evidence needed to make informed decisions about student learning and appropriate modifications to our curriculum. A revised plan for assessing this and other program learning outcomes is described below.

Initial assessment of Outcome 2 will be based on student work during the current (2009-2010) academic year and will be carried out during summer and fall of 2010. Outcomes 3 and 4 will be assessed during the summer and fall of 2011 and 2012. Once assessment of all four outcomes has been phased in, it is anticipated that evidence pertaining to each outcome will be collected and assessed every year but that programmatic changes will normally be made on a four-year cycle based on evidence collected during all four years.

B. Program learning outcomes

Our program learning outcomes are based in part on the "student skills" specified as goals for chemistry undergraduate programs by the American Chemical Society's Committee on Professional Training. We have refined and reorganized their list and made some other modifications to reflect the character of Merced's program. The Program Learning Outcomes specified for the Chemical Sciences major are:

1. Fundamental knowledge and skills. Students are able to describe the major concepts and theoretical principles in chemistry. They can identify the central ideas underlying the principal

subfields of chemistry-- analytical, inorganic, organic, and physical chemistry--as well as the broader interdisciplinary subfields of biological, environmental and materials chemistry. Students are able to operate modern chemical instrumentation, perform chemical syntheses and carry out other essential chemical experiments with strict adherence to sound laboratory techniques as well as good safety and hygiene practices. They know how to use modern web-based methods to effectively search the scientific literature.

2. *Scientific methodology*. Students have developed the ability to integrate the aforementioned fundamental knowledge and skills into scientific inquiries. They can formulate well-defined and quantitative questions, develop testable hypotheses, design and execute experiments, analyze and interpret the results and reach appropriate conclusions. They are also able to critically analyze the work of other scientists and assess its correctness, importance, and relevance.

3. *Communication and teamwork skills.* Students are able to write organized and concise reports and present technical information using electronic media, posters and oral presentations. They have developed the communication and teamwork skills that allow them to work effectively both as leaders and as team members in a group.

4. *Citizenship, ethics, role of chemistry in society*. Students have an appreciation for the role of chemistry in the global society as well as the central role chemistry plays in other scientific disciplines such as biology, medicine, environmental science, and engineering sciences. They conduct themselves ethically and responsibly in science-related professions.

These learning outcomes, along with a brief description of the major, degree requirements, and brief course descriptions with links to recent syllabi, are posted on the School of Natural Sciences web site (http://naturalsciences.ucmerced.edu/students/undergraduate/chemical-sciences) and will be updated as appropriate.

C. Evidence

Achievement of program learning outcomes will be assessed through four types of evidence: student reports from upper-division laboratory courses and CHEM 195 research courses, oral presentations given in CHEM 194, an American Chemical Society standardized exam given to graduating seniors, and an exit questionnaire given to graduating seniors. Originally we had also planned to use embedded questions on final exams, but our initial attempt to do so led us to conclude that this provided very little new information beyond that contained in the students' final course grades.

Outcome 1 (fundamental knowledge and skills) will be assessed through a combination of an externally calibrated, standardized exam (for concepts and theoretical skills) and performance in upper-division laboratory courses (for laboratory skills). We will have our seniors take the American Chemical Society's Diagnostic of Undergraduate Chemistry Knowledge exam. This is a two-hour, 60-question exam that poses a number of realistic scenarios in forensics, environmental chemistry, medicine, agriculture, materials science, *etc*. and asks several chemical questions related to each one. Results from this exam can be benchmarked against results from other institutions to give us a good idea of where our students stand. In addition, faculty teaching upper-division laboratory courses, currently CHEM 101L (Advanced Synthetic Laboratory), CHEM 114L (Instrumental Analysis and Physical Chemistry Laboratory), and CHEM 147 (Materials Chemistry Laboratory, if it is ever taught), as well as all faculty supervising CHEM 195 research courses, will be asked to evaluate each student on the laboratory-based aspects of Outcome 1 as outlined in the table below. Each student will be rated on each applicable skill on a scale of excellent, good, fair, or poor.

skill	course
Operate modern chemical instrumentation	114L 195 (as appropriate)
Perform chemical syntheses	101L 195 (as appropriate)
Adhere to safety and hygiene standards	101L 114L 195
Search the chemical literature	114L 195

Outcome 2 (scientific methodology) will be assessed through evaluation of student reports from CHEM 195 research courses. While we teach aspects of scientific methodology in several places in the curriculum (see below), independent research provides the best opportunity to assess what the student has learned. For each student enrolled in CHEM 195, the instructor and a second faculty member will evaluate each report and assign a score of excellent, good, fair, or poor for each of the four sub-objectives:

- formulate questions and develop testable hypotheses
- design and execute experiments
- analyze and interpret results
- critically analyze the work of other scientists

The instructor's evaluation should be based on the written report as well as his or her interaction with the student during the course of the research project. The second faculty

member will provide a less informed but also unbiased evaluation based solely on the written report.

Outcome 3 (communication and teamwork) will be assessed in three ways. Written communication skills will be evaluated using laboratory reports from CHEM 114L and CHEM 195. The instructor and a second faculty member will evaluate one report from each student in each course and assign a score of excellent, good, fair, or poor. Oral communication skills will be evaluated based on student seminars presented in the new CHEM 194 course, which we plan to make a requirement for all Chemical Sciences seniors. The course instructor and another faculty member will evaluate each seminar as excellent, good, fair, or poor. Finally, teamwork skills will be evaluated by performance in the laboratory in CHEM 101L, CHEM 114L, and CHEM 195. The instructor of each course will be asked to assign each student a score of excellent, good, fair, or poor based on his/her ability to work with others in a laboratory setting.

Outcome 4 (ethics and citizenship) will be evaluated through an exit survey given to senior majors during CHEM 194 which will contain questions designed to probe understanding of and attitudes related to ethics and citizenship. Details of the survey are still under development.

D. Process

Collection of coursework- and research-based evidence and its assessment will be performed at the end of each semester, including summer session for research courses. The ACS exam and the exit survey will be administered to graduating seniors at the end of spring semester, during CHEM 194 once that course becomes a program requirement. Until that time, faculty supervising seniors in CHEM 195 will be asked to administer the exam and exit survey to their research students.

After assessment of all four outcomes has been phased in, the assessment results will be critically evaluated and action will be taken every four years. By averaging data over four years, we hope to avoid making excessively large or numerous changes in the program based on small amounts of data or an anomalously weak single class. Actions to be taken may involve adding or deleting courses, changing course content, sequence, or prerequisites, or changing the instructors assigned to particular courses. Substantive changes to individual courses or to the program will require formal approval by the faculty of the School of Natural Sciences and then by the campuswide Undergraduate Council. These change requests will be submitted before the end of fall semester, allowing adequate lead time for any course or program modifications to take effect the following fall semester.

E. Participants

Collection and analysis of coursework- and research-based evidence will be carried out by the chemistry program faculty each semester. While CHEM 101L, 114L, 147 if offered, and 194 are the key courses providing assessment data, most of the chemistry faculty supervise one or more CHEM 195's each semester. The "second faculty members" involved in evaluating laboratory and research reports (see above) will be chosen to distribute the work as equally as possible among the chemistry faculty, with a somewhat lighter load for untenured faculty. School of Natural Sciences staff will be tasked with ordering the ACS exams and, perhaps, with scoring them based on a multiple-choice key. The exit survey will be written by the chemistry program faculty.

The chemistry program faculty will meet annually to disseminate the results of that year's assessment and discuss possible changes to the assessment process or obviously needed changes to the curriculum. The faculty will convene a more thorough curriculum review every four years based on review of four years' worth of assessment data. Changes in courses or program requirements must be proposed and justified by the chemistry group faculty, approved by the Natural Sciences curriculum committee and, if substantive, by vote of the full Natural Sciences faculty, and finally approved by the campuswide Undergraduate Council. Authority for making teaching assignments rests with the Dean of Natural Sciences, but the recommendations of the program faculty are usually accepted.

Staff from the School of Natural Sciences, in consultation with the program faculty, are responsible for publicizing course syllabuses, program learning outcomes, and information about assessment. The Natural Sciences web site contains brief descriptions of each major, learning outcomes, degree requirements, and lists of all courses with links to recent course syllabuses (http://naturalsciences.ucmerced.edu/students/undergraduate/chemical-sciences).

F. Minor

The Chemical Sciences minor was originally defined to have a single Program Learning Outcome, which was the same as Outcome 1 for the major. Upon further reflection, we have recognized that this outcome is too ambitious in view of the small number of upper-division chemistry courses required for the minor, so we have modified it. The new Program Learning Outcome for the Chemical Sciences minor (pending Undergraduate Council approval) is:

Fundamental chemical knowledge. Students are able to describe the major concepts and theoretical principles in chemistry. They can identify the central ideas underlying the principal

subfields of chemistry-- analytical, inorganic, organic, and physical chemistry--as well as the broader interdisciplinary subfields of biological, environmental and materials chemistry.

The corresponding PLO for the major is being assessed through the ACS Diagnostic of Undergraduate Chemistry Knowledge exam. The same level of breadth and depth of knowledge cannot be expected for the minor because of the small number of advanced chemistry courses required. Assessment for the minor is still under discussion by the faculty.

G. Self-evaluation of assessment plan based on WASC criteria

Comprehensive List: The Chemical Sciences PLOs can be categorized as "Developed". They contain a well-organized, complete set of outcomes based on national disciplinary standards from the American Chemical Society. They also take into account relevant institution-wide outcomes such as communication and ethics. They fail to meet the "highly developed" level because the faculty have not yet discussed and agreed on explicit criteria for assessing mastery of each outcome.

Assessable Outcomes: The Chemical Sciences PLOs are probably best described as "Emerging". Although most of them do indicate how students can demonstrate learning, PLO #4 in particular is quite problematic in this regard.

Alignment: We would describe the Chemical Sciences PLOs as "Developed". All PLOs are addressed in the curriculum and everything in the curriculum is responsive to the PLOs. Most but not all of the PLOs are developed at increasingly high levels as students move through the curriculum.

Assessment Planning: We consider the Chemical Sciences assessment planning to be at the "Developed" level. We have a multi-year assessment plan that identifies when each outcome will be assessed and how the results will be analyzed and used to improve the curriculum. It is not "Highly Developed" because it is not yet clear how well the chosen methods of assessment will work or how sustainable the approach is.

The Student Experience: The Chemical Sciences program falls into the "Emerging" category in this regard. We have not done a very thorough job of communicating overall program outcomes to our students. Although program outcomes are available in the catalog and on various web sites, most course syllabi contain only course learning outcomes and do not link them to program outcomes.

III. ALIGNMENT OF INSTITUTIONAL AND PROGRAM GOALS/OUTCOMES

A. Program and Institutional Goals/Outcomes

The Chemical Sciences major, with its emphasis on research, fits very well into UC Merced's mission as a student-centered research university. All of our majors are required to take at least two units of CHEM 95/195 (Undergraduate Research), and most of them take considerably more, many starting in their freshman or sophomore years. Working with a faculty member on an independent research project exposes our students to the thrill of discovery that makes doing science so rewarding. It is also an excellent venue for teaching our students new laboratory techniques, laboratory safety, teamwork, use of the scientific literature, presentation of scientific results, and scientific ethics. In addition, the vast majority of our courses are taught by research-active ladder-rank faculty who can bring examples and ideas from current research into the curriculum. Our use of non-ladder-rank lecturers has thus far been limited mainly to CHEM 1 and CHEM 2 (preparatory chemistry and first-semester general chemistry).

Although the chemical sciences program is a largely technical major and is not a primary contributor to general education at Merced, most of UC Merced's guiding principles of general education are addressed in some way in our program. The table below indicates the correspondence between our program learning outcomes and the eight guiding principles:

GE Principle → Learning Outcome ↓	Scientific literacy	Decision making	Communi-cation	Self and society	Ethics and responsi-bility	Leader-ship and team-work	Aesthetic under-standing, creativity	Develop-ment of personal potential
Fundamental knowledge and skills	X							X
Scientific methodology	X	X					X	
Communication and teamwork skills			X			X	X	X
Citizenship, ethics, role of chemistry in society		X		X	X			X

While scientific literacy is clearly the dominant GE principle addressed in the Chemical Sciences curriculum, all of the other guiding principles are at least touched upon. Decision making is encountered in determining, for example, which route to take to synthesize a particular structure or which instrumental method to use to measure a property of interest, as well as in deciding when data are complete and convincing enough to allow a conclusion to be reached. Communication is taught and assessed through written laboratory and research reports as well as oral technical seminars. Leadership and teamwork skills are exercised through laboratory experiments and research performed in pairs or larger groups. “Self and society” and “Ethics

and responsibility" are addressed by discussing some of the challenges faced by modern society whose causes and/or solutions involve chemistry (ozone depletion, renewable energy). Creativity is an ingredient of most chemical research, where by definition one is trying to solve a problem that has not been solved before. Finally, successful performance in any rigorous academic discipline, including chemistry, requires development of the student's personal potential.

B. Program and School Goals

Solutions to many of humankind's most pressing problems, from fighting disease to creating sustainable energy sources, depend upon understanding natural processes. The academic and research programs in the School of Natural Sciences create the environment for excellence in student achievement and cutting edge research in the broad areas of life, physical and environmental sciences. George Whitesides, in his 2007 Priestley Medal address, states that "Chemistry is now the natural home of many of the most engaging problems in fundamental science and of the problems in applied science about which society cares the most." Examples include unraveling the chemical mechanisms of ozone depletion, the synthesis of exciting new materials for efficient solar energy capture and storage, the development of mass spectrometric methods for analyzing biological macromolecules, and the advancement of optical methods that can access details of life processes at the single molecule level. The fundamental nature of chemistry to other fields of science is recognized by the School's requirement that all Natural Sciences majors take at least one semester of chemistry. The Biological Sciences major requires three semesters and Earth Systems Science requires two semesters. All Chemical Sciences majors must also take one semester of biology, four semesters of math, and two semesters of physics. Additionally, a broad range of chemistry-based upper-division courses in other Natural Sciences disciplines may be used to satisfy elective requirements for the Chemical Sciences major, further demonstrating the integration of our program into the School as a whole.

C. Program and Course Learning Outcomes

The curriculum map below indicates the program learning outcomes to which each of our CHEM courses contribute. Only courses that are required for one or more emphasis tracks and/or have been offered as of Spring 2010 are included. (I = introduction, D = development, M = mastery.) Note that many of the skills we consider to be at the "introductory" level are introduced in required foundational courses in mathematics, physics, and writing.

CHEM course	Fundamental knowledge and skills	Scientific methodology	Communication and teamwork skills	Citizenship, ethics, role of chemistry in society
2 (Gen chem I + lab)	I	I	I	I
8 (Organic I + lab)	D	D	D	I
10 (Gen chem II + lab)	D	D	D	I
100 (Organic II)	M			I
101L (Synthetic lab)	M	D	D	D
111 (Biochem I)	D			I
112 (Quantum/ spectroscopy)	M			I
113 (Thermo/ kinetics)	M			I
114L (Physical/ instrumental lab)	M	D	M	D
115 (Instrumental analysis)	M			I
120 (Inorganic)	M			I
122 (Biochem II + lab)	M	D	D	D
147 (Materials lab)	M	D	M	D
95/195 (Research)	M	M	M	D
194 (Ethics & communication)			M	M

The emphasis of the program is on the fundamental knowledge and skills that are specific to the discipline. All of our chemistry courses except CHEM 194 address this outcome and most of the upper-division courses aim to develop mastery of a particular area of chemistry. The skills grouped under "scientific methodology", as well as communication and teamwork skills, are addressed mainly in laboratory and research courses and courses with a laboratory component. Communication is also addressed explicitly in the new CHEM 194. Citizenship and ethics are addressed occasionally in all of our courses and more often in laboratory-based courses, and explicitly in CHEM 194.