Millikin University
Student Learning in the Chemistry Major

By Ed Acheson, George Bennett, Clarence Josefson, Derrik Helfer, Anne Rammelsberg
June 1, 2006

Executive Summary

The Department of Chemistry supports the mission of the university in preparing students for professional success, democratic citizenship in a global community, and a personal life of meaning and value by producing graduates who achieve the following three chemistry-specific learning outcome goals:

1. Demonstrate the skills to solve problems and communicate through writing and speaking.
2. Discover how to integrate and apply knowledge and skills both within the chemistry community and between chemistry and other disciplinary communities.
3. Develop the capacity to address real-world scenarios in which chemistry plays a role.

Our curriculum introduces each student to the five sub-fields of chemistry recommended by the Committee on Professional Training of the American Chemical Society. These are: inorganic, organic, physical, analytical, and biochemistry. We have one faculty member for each of these sub-fields. The Chemistry curriculum incorporates the integration of theory and practice. Theory is emphasized in classroom activities while practice is emphasized in the laboratory. In some cases, courses tightly integrate the two. Every chemistry major completes a core curriculum. Depending upon their individual interests, students then select additional study in one of four areas that we call emphases: research, secondary education, biochemistry, or business.

Regardless of emphasis, undergraduate research is the keystone of the chemistry major at Millikin. It is this activity that requires the synthesis of all three learning outcome goals and therefore is the easiest to assess uniformly. Undergraduate research has four components: the proposal, the research, a final written report, and a final oral presentation. Research requires significant creative work. Excellent undergraduate research characterizes excellent chemistry programs nationwide.

We created a rubric for assessing each component of undergraduate research: proposal, performance, and presentation. We regard this first assessment as a starting point to help us plan for the future. Based on the rubrics we created for assessing the proposal, performance, and presentation of research, we rate our current status on goals 1 and 2 as "yellow light" (not at an acceptable level) and our current status on goal 3 as "green light" (at an acceptable level). While these ratings are disappointing, they are not surprising given the small numbers of students assessed. We will continue to work on ways to ensure that all our students perform at the "green light" level in the future.

Report

Goals

The Department of Chemistry supports the mission of the university in preparing students for professional success, democratic citizenship in a global community, and a personal life of meaning and value. The mission of the department is to produce graduates who achieve the following three learning outcome goals:

1. Demonstrate the skills to solve problems and communicate through writing and speaking.
2. Discover how to integrate and apply knowledge and skills both within the chemistry community and between chemistry and other disciplinary communities.
3. Develop the capacity to address real-world scenarios in which chemistry plays a role.

The successful graduate of the Department of Chemistry is not necessarily a professional chemist. For example, recent graduates are working in the chemical and pharmaceutical industry, practicing medicine or pharmacy, selling technical goods and services, running their own businesses, teaching, and working in the areas of government and law, among other things.

Snapshot

The Department of Chemistry is approved by the Committee on Professional Training (CPT) of the American Chemical Society (ACS). The department consists of five full-time faculty members representing the five major sub-fields of chemistry: analytical chemistry, biochemistry, inorganic chemistry, organic chemistry, and physical chemistry. All chemistry majors choose one of four emphases: biochemistry, business, research, or secondary education. Students complete 23 credits of common core courses plus additional courses specific to the emphasis. Our CH121-General Chemistry course serves approximately 250 students per year, including students majoring in chemistry, biology, nursing, elementary education, athletic training, physical education, psychology, and exploratory studies, *inter alia*. Our CH224-Inorganic Chemistry and CH301/302-Organic Chemistry courses each serve approximately 50-65 students per year, primarily chemistry and biology majors. Over the last ten years, approximately nine majors per year have graduated with chemistry degrees. The number of graduates has grown over the past two years to 12 in 2005 and 15 in 2006, in part due to our new science center. Slightly fewer than half of our graduates pursue advanced degrees.

The Department of Chemistry resides in the 83,000-square-foot Leighty-Tabor Science Center, which opened in the spring 2002 semester. We also recently joined Midwestern University in a dual-acceptance pre-pharmacy agreement. In terms of curriculum, our most recent initiatives have been in course delivery, specifically the Block CH121, designed for students with limited chemistry backgrounds, that meets five days a week for half the semester. The block concept was extended to our CH203/205—Essentials of Organic and Biochemistry service course during the spring 2005 semester.

Beginning with the fall 2005 semester, we instituted a math proficiency requirement for CH121 enrollment. In terms of staff, the department was reduced from 5.5 FTE to 5 FTE beginning in the fall 2004 semester.

The Learning Story

Three hallmarks characterize the typical learning experience provided through the chemistry major:

1. **Do Chemistry as Chemists Do It**
   Students use modern instruments from the first lab class in the first year; repeating experiments should be normal, not remedial. The desired outcome of an experiment is an accurate, reproducible, unambiguous result, not a predestined "right one."

2. **Modern Chemistry is Integrated**
   Chemists address problems with concepts and techniques that span the various sub-fields of chemistry. Moreover, biologists, nurses, psychologists, and physicians also regularly use these same concepts and techniques.

3. **The Main Goal of Laboratory is Tackling a New Problem Capably**
   We design experiments to develop maximum independence, not maximum coverage.

The curriculum map is included as Appendix 1. Our core curriculum introduces each student to four of the sub-fields of chemistry while providing a foundation in essential laboratory techniques. The additional courses in each emphasis then offer students more specialized technical training. Regardless of emphasis, undergraduate research is the keystone of the chemistry major at Millikin. It has four components, including the proposal, the research, a final written report, and a final oral presentation.

The proposal is part of the course CH254—Introduction to Research. The proposal must be a project suggested by a faculty member or an industrial mentor (with consent of a faculty member). The proposal includes a background section that shows careful reading of primary journals. Ideally, the research should be connected to a real-world problem.

In terms of the actual research, we look for consistent work over time. The student should try to do a project that might be presented at a meeting, especially the National Meeting of the ACS. The lab notebook is assessed to determine the quality and quantity of work. The best projects create new knowledge.

In CH482—Senior Seminar, the student writes the final report and presents the work orally. This presentation includes an explanation of the context of the work, the techniques used, the data, and what the results mean. The student is also expected to reflect on what he or she learned about chemistry in the process.

Just as the curriculum helps the department achieve goals for student learning outcomes and helps students actualize their plans of study, so too does the advising process. Advising in the Department of Chemistry facilitates and integrates reasoned

choices that promote the student's growth as a person and as a major. In order to realize this mission, we try to help students:

1. Develop plans of study for successfully achieving their degree and career goals,
2. Select courses each semester to progress toward fulfilling their plans of study,
3. Use the resources and services on campus to assist in fulfilling their plans of study, and
4. Graduate in a timely manner.

At least once a semester, the student meets in person with the academic advisor to discuss fulfillment of the plan of study.

Assessment Methods

Prior to 2005, our methods of assessment primarily evaluated achievement of learning outcome goal #1 above. These methods included the ETS major field examination administered to senior majors, ACS standardized examinations administered to students in specific courses, and maintenance of our CPT-approved status. As a result of developing this self-study report, however, we decided that assessment of the four aspects of undergraduate research is the most informative way to assess the three learning outcome goals. The research project is the culminating event of each goal as well as the climax of each emphasis within the major. We have created rubrics for assessing the proposal, performance, and presentation of research. These rubrics are attached as Appendix 2.

Assessment Data

Department goal 1 will be assessed in CH482 using the "Final Presentation" rubric. Department goal 2 will be assessed in CH254 using the "Proposal" rubric. Department goal 3 will be assessed in CH391/491 using the "Research" rubric.

As noted above, each department learning goal will be assessed by evaluating student learning in one class. Five to 10 students from each class will be randomly selected for evaluation. As a general rule, one-half of a given class will be selected; for classes with fewer than 5 students, all students in the class will be evaluated; for classes with greater than 20 students, 10 will be randomly selected.

The grading rubrics used to assess each learning goal have 3 categories: Excellent, Adequate, and Nominal. The range of points possible on each rubric is 2-14. A student ranked "adequate" on all evaluative items would have a numeric score of 8. All students should be ranked "adequate" (i.e., have a minimum score of 8 on each rubric) if the department goals are being achieved. Realistically, however, there may be students, for a variety of reasons, who are ranked less than "adequate". Considering the small sample sizes typically available in a given class, the following assessment criteria will therefore be used to evaluate student progress in achieving department learning goals:

> "Green light" (an acceptable level or clearly heading in the right direction and not requiring any immediate change in course of action): 80% or more of the students ranked "adequate" or "excellent";
> "Yellow light" (not an acceptable level; either improving, but not as quickly as desired or declining slightly. Strategies and approaches should be reviewed and appropriate adjustments taken to reach an acceptable level or desired rate of improvement): 60% to 80% of the students ranked "adequate" or "excellent"; and
> "Red light" (our current status or direction of change is unacceptable. Immediate, high priority actions should be taken to address this area): fewer than 60% of the students ranked "adequate" or "excellent".

For reporting purposes, a rubric numeric score of 13-14 will be considered "excellent"; a score of 8-12 will be considered "adequate"; and a score less than 8 will be considered "nominal".

Assessment data are listed in the tables below.

Table 1.

Department Goal 1: Demonstrate the skills to solve problems and communicate through writing and speaking.

Rubric Category	Percentage of students in category
Excellent	0
Adequate	75
Total of above (used for rating)	75
Nominal	25
Number of students evaluated	8
Average numeric score	8.75

Rating for goal 1: “Yellow light”.

Table 2.

Department Goal 2. Discover how to integrate and apply knowledge and skills both within the chemistry community and between chemistry and other disciplinary communities.

Rubric Category	Percentage of students in category
Excellent	22
Adequate	44
Total of above (used for rating)	66
Nominal	34
Number of students evaluated	9
Average numeric score	9.67

Rating for goal 2: “Yellow light”.

Table 3.

Department Goal 3. Develop the capacity to address real-world scenarios in which chemistry plays a role.

Rubric Category	Percentage of students in category
Excellent	13
Adequate	75
Total of above (used for rating)	88
Nominal	12
Number of students evaluated	8
Average numeric score	10.1

Rating for goal 3: “Green light”.

Analysis of Assessment Results

At first glance, "yellow light" (not an acceptable level) on two of three assessment criteria might seem to be cause for concern. While we are not overly pleased with the results, we are not terribly surprised by them, either. With the small sample size used this year, two "outlying" students would be (and was) enough to drop the assessment into the "yellow light" category. The average numeric score for all three criteria is above 8, indicating *on average* we are meeting our learning goals. The questions then become: 1. Why do we have outlying students? and 2. What can we do to help the "nominal" student achieve at a higher level?

The answer to the "why" question is both simple and complex. Students are individuals with their own unique talents, abilities, and motivations. We as teachers have only a limited ability to influence the performance of a given student. Yes, we can impact the ability of a student; yes, we can impact the motivation of a student. Ultimately, however, motivation and the application of one's talents must come from within the individual. As we look at the particular students who were outliers for goals 1 and 2, we were not surprised by these results. The students who were outliers had the ability and talent to perform at an "adequate" level, but for whatever reasons, did not have the motivation to do so.

What can we do to help the outliers? Again, the answer is both simple and complex. The simple answer is: give them more individual attention. That simple answer, however, is complicated by the reality of class size. The classes that were used this year to evaluate goals 1 and 2 were relatively large for upper division courses in the Chemistry Department. It becomes harder to provide students with the individualized attention they may need as class size gets larger.

Goal 3, "green light", is assessed by evaluating the actual research work students perform. For the most part, students are doing well with their research projects. Only one student evaluated this year failed to perform at an adequate level. This particular student was afflicted with a severe case of senioritis during the spring semester. His work during the fall semester was more than adequate, but dropped off significantly during the spring semester; his overall evaluation therefore fell into the "nominal" category. While we as faculty constantly evaluate how we handle research in terms of projects for students, numbers of students supervised per faculty member, how research is credited in teaching loads, etc., we are pleased with student learning in this area and do not plan any major changes in the immediate future.

Our program is accredited by the Committee on Professional Training of the American Chemical Society—the benchmark of a quality chemistry program. We therefore know our program is a high quality program. Our graduates leave Millikin and go onto successful and distinguished professional careers. We therefore know our students gain a quality education that prepares them for professional success. Our goal now is to seek ways to deal with our weaker students to help improve their learning.

Improvement Plans

Our improvement plan at this point might be described as "watchful waiting" with a tweak. It is difficult for us to draw any solid conclusions on how we might improve based on this first year's data. On average, our students are learning well. We must continue to do the things that have been successful for our students. Our "watchful waiting" will therefore be to continue doing the same things we have done in the past, but continue to collect the same data for another two years. At that point, with three years' worth of data, we should be better able to identify trends that may need to be addressed in more depth.

We must also look into ways of dealing with the "outlier" student. One way to do that, we believe, is to provide for closer student-faculty interaction. The best way to do that at the moment is to limit the number of research students each faculty member must mentor. We will do that by placing enrollment limits on our research courses. Limiting the number of research students per faculty member will allow faculty to more closely interact with students on their projects. We assess student learning based on not just the research itself but also on the original research proposal and the presentation of that research. By limiting the number of students each faculty member supervises, we hope that the additional time for student-faculty interaction and feedback will result in increased student performance on learning goals 1 and 2. One year from now, we will evaluate how well that worked from both the students' and faculty's perspectives.

Appendix 1: Curriculum Map for Chemistry

University Goals

1. Professional success
2. Democratic citizenship in a global environment
3. A personal life of meaning and value

Department Goals

1. Demonstrate the skills to solve problems and communicate through writing and speaking.
2. Discover how to integrate and apply knowledge and skills both within the chemistry community and between chemistry and other disciplinary communities.
3. Develop the capacity to address real-world scenarios in which chemistry plays a role.

Curriculum Map (Lecture/Lab) (**Bold** = Chemistry core courses)

Year	Dept. Goal 1	Dept. Goal 2	Dept. Goal 3
1	CH121/**151** **CH224/CH152**		
2	**CH222/CH253** **CH301/251** **CH302**/CH252		
3	**CH303**/CH351 CH304 CH432	**CH254** CH331/CH354	**CH391-392**
4	CH353 CH406 CH420/CH352 **CH482**	**CH482**	CH470 **CH491-492**

Appendix 2: Evaluation Rubrics for Undergraduate Research

The proposal: grading done by faculty member teaching Introduction to Research

	Excellent	Adequate	Nominal
Process	**5 points]** A thorough explanation of previous work to a clear study question followed by analysis of previous work to synthesis into a coherent proposal.	**[3 points]** Shows some evidence of the process: explanation to conjecture to analysis to synthesis but incomplete.	**[1 point]** Restates some general ideas or issues but shows no evidence of analysis.
Connection	**[3 points]** A good proposal has a history. This includes your personal experience, it has a real-world context, and it has a connection to previous work both at Millikin and in the literature.	**[2 points]** Shows you understand the history of the proposal by examining some of your own experiences in the past as they relate to the proposal but otherwise incomplete.	**[1 point]** Minimal connections made.
Readings	**[4 points]** In-depth synthesis of thoughtfully selected aspects of readings related to the proposal. The readings are significant and appropriate at the college level. While you may use data and primary texts collected from the internet, the majority of readings are from library sources. Makes *clear* connection between what is learned from readings and the proposal.	**2 points]** Goes into more detail explaining some specific ideas or issues from readings related to the topic. Makes general connections between what is learned from readings and the topic.	**[1 point]** You show some evidence of reading about the topic and are able to state some general ideas or issues from readings related to the topic. But there is no evidence of library research beyond the class textbook, secondary sources and the internet.
Grammar	**[2 points]** No spelling or grammar errors.	**[1 point]** Few spelling and grammar errors.	**[0 points]** Many spelling and grammar errors, use of incomplete sentences, inadequate proof reading.

Research: evaluation by faculty mentor using notebook

	Excellent	Adequate	Nominal
Quantity	**[5 points]** You work consistently over the entire research period with clear evidence of significant weekly work. You consistently report to faculty mentor.	**[3 points]** You work consistently most of the time but miss from time to time	**[1 point]** You try to cram the work into a short period
Quality	**[3 points]** You work efficiently with some measure of success. Your work is worthy of submission to an off-campus conference	**[2 points]** You have some success but not at the level worthy of an off-campus conference	**[1 point]** Work is not worth crowing about.
Notebook	**[4 points]** Notebook is clearly written and contemporaneous.	**2 points]** Notebook is contemporaneous but hard to follow.	**[1 point]** Your notebook is incomplete and a mess.
Safety	**[2 points]** You consistently use safe practice and clean up your work area.	**[1 point]** You consistently use safe practice but leave a mess behind.	**[0 points]** You work in an unsafe manner.

Final Presentation: written and oral report of results

	Excellent	Adequate	Nominal
Report	[5 points] A report having quality that might be submitted to a research journal. Includes background, data and methods, results, and discussion. Includes suggestion for further work.	[3 points] A good report but missing some aspect of an excellent report	[1 point] A report having minimal value
Oral Presentation	[5 points] Clear, confident presentation. Audience questions are answered in a way to illustrate a complete knowledge of the topic.	[3 points] A good presentation but lacking clarity or confidence.	[1 point] An awkward, weak presentation but a presentation made nevertheless.
Reflection	[2 points] A valuable reflection on the complete undergraduate chemistry experience.	[1 point] Some attempt at reflection but incomplete	[0 points] No reflection
External presentation	[2 points] Presented results at an off-campus conference or meeting	[1 point] Presented a good poster at the Millikin undergraduate research symposium	[0 points] No presentation

Appendix 3: Student Learning Evaluation Forms

Millikin University
Department of Chemistry
Student Learning Evaluation

Evaluation of: Department Goal 1.
"Demonstrate the skills to solve problems and communicate through writing and speaking."
Item evaluated: Final Presentation (written and oral report of results)
Student name:
Date of evaluation:
Evaluation by: Faculty member teaching Chemistry Seminar and/or Faculty Mentor
Faculty name:

Item	Criteria			Student Score
	Excellent	Adequate	Nominal	
Report	[5 points] A report having quality that might be submitted to a research journal. Includes background, data and methods, results, and discussion. Includes suggestion for further work.	[3 points] A good report but missing some aspect of an excellent report	[1 point] A report having minimal value	
Oral Presentation	[5 points] Clear, confident presentation. Audience questions are answered in a way to illustrate a complete knowledge of the topic.	[3 points] A good presentation but lacking clarity or confidence.	[1 point] An awkward, weak presentation but a presentation made nevertheless.	
Reflection	[2 points] A valuable reflection on the complete undergraduate chemistry experience.	[1 point] Some attempt at reflection but incomplete	[0 points] No reflection	
External presentation	[2 points] Presented results at an off-campus conference or meeting	[1 point] Presented a good poster at the Millikin undergraduate research symposium	[0 points] No presentation	
Total Points (14 max.)				

Millikin University
Department of Chemistry
Student Learning Evaluation

Evaluation of: Department Goal 2.
"Discover how to integrate and apply knowledge and skills both within the chemistry community and between chemistry and other disciplinary communities."
Item evaluated: The research proposal
Student name:
Date of evaluation:
Evaluation by: Faculty member teaching Introduction to Research
Faculty name:

Item	Criteria			Student Score
	Excellent	Adequate	Nominal	
Process	**[5 points]** A thorough explanation of previous work to a clear study question followed by analysis of previous work to synthesis into a coherent proposal.	**[3 points]** Shows some evidence of the process: explanation to conjecture to analysis to synthesis but incomplete.	**[1 point]** Restates some general ideas or issues but shows no evidence of analysis.	
Connection	**[3 points]** A good proposal has a history. This includes your personal experience, it has a real-world context, and it has a connection to previous work both at Millikin and in the literature.	**[2 points]** Shows you understand the history of the proposal by examining some of your own experiences in the past as they relate to the proposal but otherwise incomplete.	**[1 point]** Minimal connections made.	
Readings	**[4 points]** In-depth synthesis of thoughtfully selected aspects of readings related to the proposal. The readings are significant and appropriate at the college level. While you may use data and primary texts collected from the internet, the majority of readings are from library sources. Makes *clear* connection between what is learned from readings and the proposal.	**2 points]** Goes into more detail explaining some specific ideas or issues from readings related to the topic. Makes general connections between what is learned from readings and the topic.	**[1 point]** You show some evidence of reading about the topic and are able to state some general ideas or issues from readings related to the topic. But there is no evidence of library research beyond the class textbook, secondary sources and the internet.	
Grammar	**[2 points]** No spelling or grammar errors.	**[1 point]** Few spelling and grammar errors.	**[0 points]** Many spelling and grammar errors, use of incomplete sentences, inadequate proof reading.	
Total Points (14 max.)				

Millikin University
Department of Chemistry
Student Learning Evaluation

Evaluation of: Department Goal 3.
"Develop the capacity to address real-world scenarios in which chemistry plays a role."
Item evaluated: Research (evaluation by faculty mentor using notebook)
Student name:
Date of evaluation:
Evaluation by: Faculty mentor
Faculty name:

Item	Criteria			Student Score
	Excellent	Adequate	Nominal	
Quantity	**[5 points]** You work consistently over the entire research period with clear evidence of significant weekly work. You consistently report to faculty mentor.	**[3 points]** You work consistently most of the time but miss from time to time.	**[1 point]** You try to cram the work into a short period.	
Quality	**[3 points]** You work efficiently with some measure of success. Your work is worthy of submission to an off-campus conference.	**[2 points]** You have some success but not at the level worthy of an off-campus conference.	**[1 point]** Work is not worth crowing about.	
Notebook	**[4 points]** Notebook is clearly written and contemporaneous.	**[2 points]** Notebook is contemporaneous but hard to follow.	**[1 point]** Your notebook is incomplete and a mess.	
Safety	**[2 points]** You consistently use safe practice and clean up your work area.	**[1 point]** You consistently use safe practice but leave a mess behind.	**[0 points]** You work in an unsafe manner.	
Total Points (14 Max.)				