

# Final Project Evaluation Report

June 30, 2007

## Incorporation of Modern NMR Spectroscopy into the Chemistry Curriculum of a Four-Year Undergraduate Institution

(NSF CCLI Grant)

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## Introduction

In September 2004, the National Science Foundation awarded the State University of New York College at Brockport (SUNY Brockport) a \$127,201 federal grant through the Course Curriculum Laboratory Improvement (CCLI) program for a thirty-six month period. The Principal Investigators responsible for this project were Drs. Markus Hoffmann, Mark Heitz and Margaret Logan of the Department of Chemistry at SUNY Brockport. The purpose of this project was to acquire a 300-MHz Nuclear Magnetic Resonance (NMR) spectrometer that could be used by chemistry faculty at this four-year liberal arts college to enhance the undergraduate chemistry curriculum, enable more innovative teaching practices, and support greater research opportunities for undergraduate students and faculty at SUNY Brockport.

In the grant proposal narrative, the PIs cited several examples of the intellectual merit of this project. They noted that the acquisition of the new NMR instrument would empower the faculty to implement pedagogical practices that are consistent with an inquiry-based approach to teaching science as advocated for in the National Science Education Standards (NRC, 1996). In addition, undergraduate students in the organic, analytical, physical and advanced organic chemistry laboratory courses would have unique opportunities to experience project-based experiments utilizing the NMR instrument that promote team learning, active student engagement in problem-solving and the development of experimental techniques that are essential for the scientific literacy of chemistry professionals.

Beyond the immediate improvements in the chemistry curriculum, the PIs further indicated that the new NMR instrument and associated project activities would provide new training opportunities for faculty and students to broaden the infrastructure for research and education at SUNY Brockport, result in a significant increase in the nature and extent of research-relevant experiments within the various upper-level chemistry courses, and foster an expanded research and educational partnership between the College and local industry.

## The Evaluation Plan

An evaluation team from Syracuse University was contracted to audit the outcomes of the project in relationship to the major objectives described in the grant proposal. The evaluation team consisted of Dr. John W. Tillotson, Associate Professor of Science Education at Syracuse University, and Monica J. Young, NSF IMPPACT Project Director at Syracuse University.

The evaluation plan was based on a Program Logic Model for Interventions (Yarbrough, 1994) which provides an effective model for examining projects where interventions are planned that should lead to specific changes in the program structure and outcomes. Given that the project PIs identified several interventions that were to result from the incorporation of the new NMR instrument into the chemistry curriculum and research program at SUNY Brockport, this evaluation model was deemed to be the most appropriate to determine the effectiveness of these curricular and programmatic changes.

The Program Logic Model gathers information concerning:

- Contextual background information and program needs
- Goals and objectives of the project
- Resources that are devoted to the project
- Project activities and interventions
- Intended and unintended project outcomes from the perspective of various stakeholders.

The evaluation criteria that were used to judge the quality and impact of this project were based on the extent to which each of the major project objectives were met. Specifically, the evaluation criteria included: 1) the quality and extent of faculty and student training on the new NMR instrument; 2) the degree to which the laboratory and research experiences for undergraduate students now reflect an inquiry-oriented approach to learning science; 3) the growth of students' chemistry knowledge and their understanding of the nature of science; 4) the extent to which authentic, problem-based curriculum materials were developed and implemented within the targeted chemistry courses; and 5) the impact of the project on faculty recruitment and collaborations with local industries.

To measure the overall impact of the project initiatives, a combination of quantitative and qualitative evaluation methods were employed (See Appendix 1). Qualitative methods included: in-depth interviews with the project stakeholders, focus group interviews with undergraduate chemistry majors, site visits, students' written responses on the Views of the Nature of Science (VNOS) instrument (Lederman, et al, 2003), and document analysis of course syllabi and curriculum materials. Quantitative methods included pre and post surveys of students' understanding of the nature of science and scientific

research using selected items drawn from the Test of Understanding Science (TOUS) (Klopfer & Carrier, 1970) administered to equivalent groups of undergraduate chemistry majors in the targeted courses involved in the project.

### Evaluation Timeline

Project evaluation work began during the fall of 2004 based on an initial series of phone conversations with the Project PI, Dr. Hoffmann, about the project's funding approval and tentative timeline of proposed activities. The evaluation team worked to obtain human subjects data collection approval from the Syracuse University Office of Research Integrity and Protections in order to begin the evaluation process. This permission was officially granted during the spring of 2005 and was renewed annually (see Appendix 2).

During the spring of 2005, the evaluation team conducted a two-day site visit on the SUNY Brockport campus to meet with the Principal Investigators to discuss the evaluation plan, conduct initial interviews with key faculty, conduct a focus group interview with undergraduate chemistry majors, and to tour the existing chemistry department facilities. Particular attention was placed on examining the existing NMR facilities and equipment prior to the acquisition of the new 300-MHz NMR instrument.

During the initial evaluation site visit, the evaluators shared with the Project PIs the VNOS and TOUS instruments that were to be used to gather baseline data from undergraduate chemistry students in the targeted courses at the end of the spring 2005 semester concerning their views about the nature of science and scientific research prior to any curricular changes or the installation of the new NMR instrument. These data were gathered from students enrolled in the organic, analytical, and physical chemistry courses during that semester.

The evaluation plan identified in the grant narrative called for data collection in year 1 and year 3 of the project. However, the evaluation team and Project PIs felt it was important to gather formative evaluation data throughout the project to assist in identifying any project revisions that might lead to more effective outcomes. Thus, phone interviews continued throughout the 2005-2006 academic year and a second site visit was made to the SUNY Brockport campus during June 2006 for ongoing evaluation purposes. The initial evaluation outcomes for project activities through June 2006 were described in detail in an interim report that was provided to the Project PIs during the summer of 2006.

The evaluation team made its final site visit to the SUNY Brockport campus in May 2007 to conduct post-project interviews with each of the PIs and to carry out a focus group interview with a group of chemistry students who had

participated in various research projects and laboratory activities using the new NMR instrument. The evaluators also collected copies of course syllabi and other relevant materials that demonstrated how the curriculum within various chemistry courses had been modified to include more inquiry-oriented learning experiences involving the new NMR instrument. The Project PIs provided the evaluation team with the raw data from the post-administration of the VNOS instrument and the TOUS survey. The analysis of the evaluation data was completed during May and June of 2007 resulting in the production of this final project evaluation report which synthesizes all of the information gathered over the past thirty-six months related to the project objectives and outcomes.

### **Contextual Background and Program Needs**

Throughout the evaluation efforts, a major goal was to understand the pre-existing contextual factors and program needs within the SUNY Brockport Department of Chemistry related to this grant initiative. Based on the data gathered initially, it was clear that there was a significant need for the new NMR instrument and associated curriculum and research program revisions.

The Chemistry Department at SUNY Brockport is experiencing a major transition period: three new junior faculty hires have occurred in the past eight years. An outside department chair was hired to begin in fall 2007, and a search to replace a just retired faculty member is anticipated for the coming academic year. Due to the department demographics, additional searches to replace retiring faculty are anticipated within the next 1-4 years. The influx of the new faculty resulted in an increased interest in revamping the existing chemistry curriculum and undergraduate research program based on the interviews conducted with department faculty and chemistry majors during the early stages of the grant project. The three Project PIs are the three recent hires, with strong research credentials and a clear commitment to effective teaching. The students interviewed during both the initial and final focus group interviews supported this assessment citing the efforts by these faculty members to stress the importance of understanding the chemistry concepts taught in their courses and labs versus just memorizing facts. The interviews with the faculty also suggested that each of the PIs had a real sense of the importance of engaging, student-centered science instruction to support student learning and career development in chemistry.

In addition, the Chemistry Department's facilities and infrastructure were enhanced in many significant ways during the time period in which this grant project was carried out. All of the computers in the faculty offices and the student computer lab were replaced and networked so that experimental data could be remotely analyzed from various stations within the building. Several major research instruments were purchased from internal and external sources

including a time-resolved module for a research grade fluorescence spectrometer and a new high performance liquid chromatography unit.

Both the chemistry students and the faculty we interviewed throughout the evaluation effort described the Chemistry Department as having small classes and close working relationships between faculty and students. The students felt as if they were frequently encouraged to participate in undergraduate research experiences offered by the faculty and that they were comfortable in approaching any of the faculty about their work and any research opportunities available for students. Students also stated that they were given opportunities to present the outcomes of their research at various local, state and national science conferences. The data on chemistry program graduates from SUNY Brockport provides clear evidence that the program is successful in promoting continued work and education in science related career fields for the diverse body of students it serves. Data reported in the grant narrative indicate that nearly all of the 85 recent chemistry graduates in the past ten years have pursued science-related careers with 43 continuing on to pursue graduate degrees.

The Chemistry Department has also maintained strong research ties with the Rochester Midland Corporation, resulting in funding for students to participate in summer research internships. There was also other recent, albeit short term support for undergraduate research from local industrial partners including RCAg Industries, Johnson & Johnson and Bausch and Lomb Corporation.

The chemistry program at SUNY Brockport had maintained its certification through the American Chemical Society (ACS). However, the ACS now recommends the hands-on use of an NMR spectrometer as part of their guidelines, given the central role that NMR plays in the skill set of professional chemists. Based on the initial faculty and student interviews, as well as the site tour conducted during the spring of 2005, the previous NMR instrument was inadequate to provide students and faculty with the necessary capabilities to carry out meaningful lab experiments or to conduct ongoing research involving NMR techniques. Thus, the new NMR instrument provided through this CCLI grant has assisted SUNY Brockport in meeting the high standards set forth by the ACS related to undergraduate chemistry preparation.

Faculty initially reported that they were often limited in terms of what lab experiments they could implement in their courses because the outdated NMR instrument lacked the capability to perform some of the more modern, authentic types of experiments they were seeking. The lack of multi-functionality of the old NMR instrument limited the faculty members' ability to plan for team-oriented, multi-stage lab experiments where separate lab groups could run different types of analysis protocols without major set-up issues each time changes were made. Similarly, faculty reported concerns about students

using the old NMR instrument independently given its frail nature and the need for faculty to be able to have it functioning for their own research purposes.

The students interviewed during our initial evaluation site visits shared the faculty member's concerns about the old NMR instrument. Students reported that a professor or trained TA were the only ones able to actually do the work of running the samples. Often when the students did have the opportunity to use the NMR in some capacity, they reported that the instrument had frequent breakdowns and the software to run the device was not user-friendly. This caused concerns for several students who reported that they were too intimidated to use the old NMR for fear they would cause it to break down and interfere with the research activities of other students or the faculty members. Students also reported that the manuals for the old NMR instrument were not helpful when they attempted to troubleshoot problems with the device.

Other concerns related to the old NMR instrument that were reported included the limited availability of spare parts for the device and the excessive amount of faculty time spent repairing or reprogramming the NMR instrument which caused a dramatic decrease in research and teaching productivity.

The faculty and students reported during our initial site visits that the poor quality of the old NMR instrument had the greatest negative impact on students in the upper division chemistry courses (such as organic, analytical, and physical chemistry) as well as those undergraduate students conducting research because of the unreliability and unpredictability of the instrument's performance.

## Goals and Objectives of the Project

The evaluation team carefully reviewed the grant proposal narrative to identify the major project goals and objectives that would serve as the foundation for the evaluation process. The major goals and objectives include:

- Adapting well-documented lab experiments in pedagogically innovative ways for the: a) organic; b) analytical; c) physical; and d) advanced organic chemistry courses at SUNY Brockport;
- Developing a two-week NMR workshop during the winter semester break that would: a) promote student engagement in the learning process through extensive hands-on experience; b) facilitate a team learning approach; and c) incorporate project-based experiments into the training process;

- Promoting ongoing efforts to incorporate relevant research experiments into the curriculum and the integration of NMR with other experimental techniques to promote scientific literacy;
- Enhancing the undergraduate research experience at SUNY Brockport and maintaining the ACS-certified chemistry program based on the following learning outcomes:
  - a) sound knowledge base relevant to the chemistry profession;
  - b) lab and professional experiences relevant to the profession;
  - c) well-developed critical thinking/problem solving skills;
  - d) ability for students to construct their own understanding; and
  - e) well-developed scientific communication skills which are all aligned with the National Science Education Standards (NRC, 1996);
- Creating course-specific revisions such as:
  - a) Introducing  $^{13}\text{C}$  spectroscopy at an earlier stage in organic chemistry lab;
  - b) using two guided-inquiry labs and project-based labs that use 2D NMR in the organic chemistry curriculum;
  - c) introducing an integrated NMR experiment in the analytical chemistry course;
  - d) establishing a two-week, all-day winter session course on NMR techniques;
  - e) incorporating NMR experiments in project-based experiments in physical methods lab course;
  - f) increasing the hands-on NMR usage of students in upper-level chemistry courses and undergraduate research activities;
  - g) providing faculty development in using the NMR instrument effectively through a training program; and
  - h) designing the curriculum so that the upper level chemistry courses will cover a different self-contained aspect of NMR spectrometry to help transfer students more easily get familiar with the techniques;
- Expanding the capacity of SUNY Brockport to attract NMR-fluent faculty candidates to Brockport and to directly enhance faculty PIs' research endeavors;
- Increasing collaboration with local industries related to summer research opportunities for undergraduate students as a result of the new NMR instrument and associated research endeavors;
- Disseminating project outcomes through articles in the Journal of Chemical Education and the Journal of College Science Teaching, conference papers, posting evaluation reports on the website of SUNY

Brockport's chemistry department, and eventually creating an instructor's manual for the NMR workshop course.

## Resources

In addition to the \$127,201 CCLI grant that SUNY Brockport received from the National Science Foundation, several other financial, physical and human resources were devoted to this project.

As mentioned previously, SUNY Brockport committed significant financial resources to the overall upgrade of the science research facilities on campus. As evidenced by Appendix F in the grant proposal narrative, the President of SUNY Brockport also committed \$99,875 in matching funds toward the NMR acquisition. The pre-existing 5 mm dual and 10 mm broadband probes as well as accessories for measurements of low temperature were kept and used with the newly purchased probes.

The newly acquired NMR instrument resulted in a renewed commitment from the Rochester Midland Corporation to support summer research internships for undergraduate students using the modern NMR instrument. The new NMR instrument proved to be an invaluable recruiting tool in hiring the new Department Chair, who is an organic chemist by training. As the hiring of new faculty members at SUNY Brockport to replace retiring faculty continues over the coming years, the availability of the upgraded NMR instrument will significantly enhance both the teaching and research agendas and likely result in numerous additional opportunities for undergraduates to participate in research experiments involving NMR spectrometry.

In terms of human resources, the faculty in the Chemistry Department at SUNY Brockport committed countless hours to the redesign of their laboratory curriculum materials to make them more project-based and relevant to the types of analyses that professional chemists conduct in the workplace.

## Project Activities, Interventions and Outcomes

The major project outcomes of this CCLI grant were determined in relationship to the core objectives outlined in the grant narrative. These primary objectives are outlined in an earlier section of this evaluation report and presented again here to frame the organization of the evaluation results. In some cases, the objectives were evaluated as a cluster given the similarity in their intent and to avoid repetition in reporting the outcomes. Our evaluation team reviewed all of the qualitative and quantitative data gathered over the past three years to determine the degree to which the intended project outcomes were achieved. In addition, we also investigated any unforeseen problems or challenges that occurred that may have interfered with the

attempts of the Project PIs to reach these goals. Based on a careful review of the data collected, the following passages detail the major project activities, interventions and outcomes.

**Objective:** Adapt well-documented lab experiments in pedagogically innovative ways for the: a) organic; b) analytical; c) physical; and d) advanced organic chemistry courses at SUNY Brockport.

**Objective:** Promote ongoing efforts to incorporate relevant research experiments into the curriculum and the integration of NMR with other experimental techniques to promote scientific literacy.

**Objective:** Create chemistry course-specific revisions such as:

- a) introducing  $^{13}\text{C}$  spectroscopy at an earlier stage in organic chemistry lab;
- b) using two guided-inquiry labs and project-based labs that use 2D NMR in the organic chemistry curriculum;
- c) introducing an integrated NMR experiment in the analytical chemistry course;
- d) establishing a two-week, all-day winter session course on NMR techniques;
- e) incorporating NMR experiments in project-based experiments in physical methods lab course;
- f) increasing the hands-on NMR usage of students in upper-level chemistry courses and undergraduate research activities;
- g) providing faculty development in using the NMR instrument effectively through a training program; and
- h) designing the curriculum so that the upper level chemistry courses will cover a different self-contained aspect of NMR spectrometry to help transfer students more easily get familiar with the techniques.

### **Evaluation Results:**

- Undergraduate chemistry students reported that they were given many options to actually choose the specific lab experiments they did in the physical chemistry course and then were asked to present what they learned to other students during the following lab class meetings. The students felt this was beneficial in that it both provided them with a richer understanding of their own specific lab learning, but also afforded them the chance to learn from their peers.
- The students interviewed noted that the use of NMR was far more integrated into the organic chemistry courses and lab courses than it had been in previous years. In particular, the students were excited that

they were able to run experiments to produce a sample of some type and then be able to use the NMR to actually verify the products they had generated. In prior years, the old NMR instrument was so unreliable that the chemistry faculty often gave students “canned data” to use in their analysis because the NMR instrument couldn’t be counted on to be used consistently for analysis purposes.

- The students interviewed noted that the new NMR instrument allowed them to develop in-depth knowledge of NMR techniques and empowered the chemistry faculty to do more with their courses and undergraduate research program to enhance the learning for students.
- Students commented that the new NMR instrument made it possible for the instructor in the organic chemistry courses to implement labs that had real-world applications where students isolated and made NMR spectra of products from everyday life. This experience added relevance to the work that the students were doing and made it considerably more interesting than the typical verification labs used in the past because of poor NMR functionality.
- Every one of the students interviewed throughout the evaluation of this project indicated that the new NMR instrument was readily accessible for their use in both coursework and in their undergraduate research activities. They also noted that the chemistry faculty members were always available to assist them with the use of the NMR instrument whenever they needed help.
- The chemistry faculty involved in this project noted that the new NMR instrument allowed them to make better selections as far as laboratory curriculum experiences for the students because the faculty members no longer needed to pick experiments that had “back-up” plans that could be used in the likely event that the old NMR instrument failed or was being repaired.
- The chemistry faculty indicated that one positive outcome of the new NMR instrument is that students are now able to see and use more of their own data versus being given contrived data sets. The students are engaged in more real-life analytical procedures and can determine the integrity of their own research results which better models authentic science research. The faculty also commented that the new NMR allows for more problem-solving opportunities for students when experiments don’t turn out the way students had planned. They can use the NMR to attempt to understand the actual products they generated and to learn from their mistakes. When coupled with other forms of chemical instrumentation, the NMR helps the students analyze their data from

- multiple perspectives to confirm or refute their interpretations. Faculty gave examples of lab experiments such as making esters, isolating essential oils in spices, carrying out “unknown product” identification labs, performing multi-step organic synthesis labs, and analyzing nail polish removers in the analytical course as places where the new NMR played a critical role in authentic student learning.
- Faculty indicated that undergraduates involved in chemistry research have a new sense of the predictability involved in conducting research experiments thanks to the new NMR and its consistent performance. This was not the case in prior years where the old NMR often resulted in students’ frustration and long delays caused by the instrument being out of service for repairs.
  - The success of the new NMR within the chemistry program revisions resulted in SUNY Brockport contributing additional internal funds to purchase an NMR simulator module to use in the various chemistry courses. This purchase was not part of the original grant project initiative.
  - Faculty teaching the analytical chemistry course noted that the new NMR instrument and revised lab experiments now allow for individual students to contribute to the overall class data set. This information can then be used to run various types of analyses and provide students with the ability to extrapolate out their findings in ways they could not do using the previous NMR device.
  - All of the chemistry faculty members interviewed were quick to point out how much better prepared the students are for future study and employment in field of chemistry given their robust involvement with the NMR instrument and its associated applications.
  - The project PIs sought out other course and curriculum revision training opportunities that benefited their work on this CCLI grant. They attended a workshop provided by Barbara Helland, a Co-PI for the NSF-funded project Scollarcity, discussing undergraduate course reconstruction. This workshop challenged professors to assess their courses, specifically addressing what the over-arching goals of each course are and how they might be better met to actively engage students in developing an understanding of the concepts.
  - The evaluation team conducted a thorough document analysis of all relevant chemistry course syllabi to look for evidence of inquiry-oriented curriculum exemplars related to the objectives identified in this grant project. The syllabi from the 2006-2007 academic year were compared

with those from the 2004-2005 academic year to look for specific changes in the course structure made possible by the new NMR instrument. Based on our review, it was clear that significant improvements and modifications have been made to these core courses with much greater emphasis placed on student involvement in authentic problem-solving and inquiry investigations. In addition, the extent to which students were actively engaged in using the NMR instrumentation for analysis purposes was substantially greater in the more recent syllabi following the acquisition of the new Bruker NMR than in years prior. The following are excerpts from various Brockport chemistry course syllabi that are illustrative of the types of inquiry-based, experiential learning now taking place:

Excerpt from Physical Chemistry Lecture CHM 405 syllabus (Fall 2006)-

Course Objectives, Learning and Organization

*"...Far beyond being knowledgeable in content material, my major underlying goal of teaching is the development of the mind of students as it manifests itself in their mental capabilities. These include the ability to rationally analyze, to deduce logical conclusions, and to creatively express thoughts orally and in writing. Within that context, the complexity of Physical Chemistry is both a challenge but also an opportunity for your intellectual development. Some time in summer 2005, I came to the conclusion that the typical lecture format is not likely to stimulate intellectual development among the students in the classroom. Thus, since then I am employing a different instructional format, away from the typical lecture mode.*

*You will be given specific reading assignments for each class. To hold you accountable for fulfilling your reading assignments and thus being prepared for class, you will be asked to take a quiz in Angle prior to class. (I will attempt to ask questions that you will easily be able to answer as long as you seriously read the assigned readings). In class, we will then discuss in-depth the content of the reading assignment by means of working through a "guided inquiry" workshop. Some of these workshops will be taken from the textbook by Moog et al.; others, I created myself. I strive for the classroom sessions to be highly interactive and lively. You are strongly encouraged to ask any questions. Realize also that the likelihood is very high that your peers experience the same difficulties with understanding the material. There is no reason to be shy, i.e., there is no such thing as a "dumb question"! Thus, my role overall will less be of a content provider but more of a mentor guiding you through the process of learning conceptually and mathematically complex content matter.*

*While we will draw from each other during the class sessions, each student will still be held individually accountable for her/his learning progress. There will be 10 quizzes during the semester, usually after a chapter is completed, as well as a mid-term and a final exam. There will also be homework assignments in parallel to the content covered in class. In order for you to comprehend the true depth and meaning of the material for yourself, it is absolutely necessary that you try to develop your own thoughts about the material that is presented in the textbook and discussed in the classroom. The homework assignments will prompt you to do so. You may view the homework sets as mini take-home exams. Thus, they will generally not be discussed in class. Since learning is in my opinion a process that involves making mistakes and discovering these mistakes, you will have a second chance for your homework assignments. However, this is not a free ticket for you to delay your homework by one*

week. In order to prevent this kind of attitude towards your homework assignments, particular rules apply to the homework assignments as outlined below under "Course Policies". The message is: work hard right away on your homework assignments! It is not so much the answer itself than the process of figuring out how to go about solving the problem that is at the heart of learning, especially in Physical Chemistry. When you study the material or do the homework assignments and encounter difficulties with the material try to narrow down as much as you can what exactly you do not understand. The more precise your question is the more likely it is that you will understand my guiding comments when you come see me for help in my office. In fact, you will often find the answers yourself by just trying to pinpoint what exactly you do not understand. As a rule of thumb, the more you struggled with a particular subject, the longer you will retain the underlying concept once you had the "aha, I got it!" experience. I am hoping that the in-class workshop sessions combined with the extensive homework assignments will provide a major means for you to experience these "aha, I got it" experiences."

### **Excerpt from Physical Chemistry Lab I CHM 408 syllabus (Fall 2006)-**

#### *"Course Objectives and Organization*

*The objectives of this first semester physical methods laboratory course are to:*

- i) Become familiar with a variety of physical measurement methods.*
- ii) Learn to collect, organize, and analyze experimental data in a structured and scientific manner.*
- iii) Learn how to present clearly and concisely the results of scientific work.*

*A scientific experiment is not completed until the results and new findings have been made public. The most common forums of presenting scientific work are through scientific papers in appropriate journals and oral presentations at technical meetings. Hence, it is important to learn how to present scientific data in these forums. Furthermore, well-developed communication skills, both written and oral, are in general vital to a scientist for a successful career. What good is it if a scientist makes a new discovery but cannot verbally communicate them to co-workers, supervisors or to peer scientists? Scientists also often need to disseminate their work to people with a different, little or even no scientific background, like managers, business partners, patent attorneys, or even the general public.*

*In this course you will be exposed to the typical steps of a "research project" including:*

- preparation for an experiment*
- execution of an experiment where you acquire experimental data*
- analysis of the data (if you can, in parallel to the data acquisition, i.e., "on the fly")*
- perhaps even repeat the experiment if the analysis reveals flaws in the data acquisition*
- write up a summary of your data and analysis (formal lab report)*

*For three out of the four experiments you will prepare a paper with a similar depth and quality as adequate for submission to a scientific journal, and for one experiment you will prepare a talk. As you can see from the schedule below, you will receive during the semester instruction and guidance in the proper analysis of experimental data, how to prepare a scientific paper and oral presentation and how to use computer programs for many of the tasks involved.*

*If any, only few scientists have the gift of immediately coming up with the best possible way of presenting their data, be it a paper, a poster or a talk. Typically,*

*even the experienced scientist has to go through many cycles of preparations and drafts before the final product is presented. Hence, the course schedule incorporates these "natural" cycles of preparation, and you will have the chance to improve (along with the grade!) all of your assignments: homework, papers and oral presentation by incorporating the feedback from your first attempt.*

*This year, there will tentatively be a group research project. The Chemistry Department has acquired a brand new 300 MHz NMR instrument with gradient capabilities. Dr. Hoffmann has plans to develop a new experiment for the Physical Methods Lab that aims at conveying the basic principles of magnetic resonance imaging (MRI) as you would encounter in the medical field. The goal of the research project will be to learn how to set up and further develop the experiment. Every student will, at some point in the semester, conduct measurements towards this research project. As the semester progresses, the data and experiences from both the Monday and the Thursday group will be compounded and made available via Angel, serving as a basis for how to proceed with the project. Further details will be discussed at the appropriate time during the semester."*

### **Excerpt from Physical Chemistry Lab II CHM 409 syllabus (Spring 2007)-**

"Course Objectives and Organization

The objectives of this second-semester physical methods laboratory course are to:

- iv) Become familiar with a variety of physical measurement methods.
- v) Learn to collect, organize, and analyze experimental data in a structured and scientific manner.
- vi) Learn how to present clearly and concisely the results of scientific work.

A scientific experiment is not completed until the results and new findings have been made public. The most common forums of presenting scientific work are through scientific papers in appropriate journals and posters or oral presentations at technical meetings. Hence, it is important to learn how to present scientific data in these forums. Furthermore, well-developed communication skills, both written and verbal, are in general vital to a scientist for a successful career. What good is it if a scientist makes a new discovery but cannot verbally communicate it to co-workers, supervisors or to peer scientists? Scientists also often need to disseminate their work to people with a different, little or even no scientific background, like managers, business partners, patent attorneys, or even the general public.

In this course you will be exposed to the typical steps of a "research project" including:

- preparation for an experiment
- execution of an experiment where you acquire experimental data
- analysis of the data (if you can, in parallel to the data acquisition, i.e., "as you go")
- preparation of a presentation (paper, poster or talk)

Oftentimes, a more careful analysis of results will indicate that it is necessary to repeat an experiment of perhaps even to revise experimental procedure or to alter experiments and experimental equipment altogether. We desire to expose you to this more realistic experience. Thus, for most of the latter part of the semester, you will be working on one project-based experiment for 5-6 lab periods. While there are

certainly clear goals to each of these projects the outcome is open-ended and might even take on a different direction as you are working on the project. As in any research project, your level of engagement and creativity will be an essential factor in moving the project forward.

If any, only few scientists have the gift of immediately coming up with the best possible way of presenting their data, be it a paper, a poster or a talk. Typically, even the experienced scientist has to go through many cycles of preparations and drafts before the final product is presented. Hence, the course schedule incorporates these "natural" cycles of preparation in two ways. Firstly, following the week of each of the first two experiments you will present in class to your peers what you have done in last week's experiment and how you would analyze the data you obtained. Secondly, you will receive feedback on your submitted manuscripts as well as your poster and oral presentations, and will have a chance to improve your performance (along with the grade!) by incorporating the feedback in a second round of submission.

The final poster presentation will actually be performed during Scholars Day, held on Wednesday, April 11 2007. Hence, you will be indirectly required to participate at this wonderful campus-wide event.

Experiments will usually be conducted with a lab partner, but work-up of data and writing is done individually. You will work each of the three experiments with a different partner, similar to the real world where you are oftentimes assigned to a team of people with a wide variety of backgrounds, personalities and work styles. Further details regarding the experiments and the course schedule will be discussed at the appropriate time during the semester."

#### **Excerpt from Organic Chemistry I CHM 305 syllabus (Fall 2006)-**

"Teaching approach: In the olden days (when I learned organic chemistry) the study of organic chemistry was an exercise in memorization, with very little attention paid to how and why chemical reactions occurred. I prefer to use an approach that I think of as the "what, how, and why" approach to the understanding of organic chemistry. Simply memorizing the "whats" does not lead to a solid grounding in organic chemistry. The "hows" and "whys" come with the examination of reaction mechanisms in the contexts of molecular structure and energetics. Fortunately, the course textbook also uses this "mechanistic approach"! The good news is that this approach provides a level of understanding of organic chemistry that is not forgotten when the test is over, and can be applied to subsequent studies in other areas, such as biochemistry or environmental chemistry. The bad news is that no matter what approach is taken, organic chemistry is still a challenging area to study, and requires significant amounts of memorization and conceptual understanding. So--study strategies are critical!"

**Objective:** Develop a two-week NMR workshop during the winter semester break that will: a) promote student engagement in the learning process through extensive hands-on experience; b) facilitate a team learning approach; and c) incorporate project-based experiments into the training process.

**Evaluation Results:**

- All of the project PIs attended a four-day training session provided by the Bruker-Biospin Corporation to learn about the various features and functions of the new NMR instrument, and two of the PI's attended a second four-day advanced training session. Upon returning to campus, the PIs have conducted their own training sessions with other SUNY Brockport faculty and scientists from the Rochester Midland Corporation who partner with SUNY Brockport on NMR research projects.
- The two-week NMR workshop for faculty and students that was originally planned for January 2006 was actually taught during the January 2007 semester break. This was necessitated by some faulty chips and software problems with the new NMR instrument that took place during the fall 2005 semester. Following the installation of the new instrument in July 2005, the PIs experienced repeated problems with the software and several circuit boards on the new Bruker NMR. This resulted in repeated service calls and significant periods of downtime where either the instrument could not be used, or it required frequent recalibration. This interfered with the chemistry faculty members' efforts to use the new NMR in their lab courses and slowed other research efforts that were underway involving both undergraduates and faculty. The bugs in the new NMR were worked out by the end of the fall 2005 semester, but it was too late to be able to effectively organize and offer the January 2006 NMR workshop as originally intended. Instead, the project PIs continued their curriculum revision efforts and relied on more individual student and TA training sessions for the spring 2006 term.
- The two-week course that was held in January 2007 included all of the planned educational experiences, as well as information on the "lessons learned" from the past two years of working with the instrument. The evaluators believe that the unintended delay of this workshop by one year was, in fact, a positive outcome given the added experience with the instrument that the workshop leaders brought to the training session after one full year of stability in using the new NMR instrument.
- Student handouts were developed by the project PIs to be used as a reference sheet in the laboratory related to how to properly use the

NMR instrument for various applications. These materials were incorporated into the winter 2007 training workshop.

- The chemistry students interviewed by the evaluation team reported that the two-week NMR workshop was a very positive experience for them. They felt as though the workshop was very thorough and gave them “opportunities to learn about the backbone of the entire NMR instrument.” These students cited the opportunities to learn about the various analysis programs that the NMR instrument could handle as being very beneficial to their ability to use the NMR instrument in their lab courses as well as in their undergraduate research experiences.
- The chemistry faculty members were equally positive about the outcomes of the winter NMR short-course. In general, they felt that the students who attended “gained a much deeper understanding of various NMR techniques and analysis protocols” as a result of their participation in the workshop. The Project PIs noted that a few of the chemistry department faculty had signed up to participate in the training but had to cancel for legitimate, unexpected reasons. Having to pay for an extra course during the winter break proved to be a significant hurdle for students to overcome which likely contributed to the smaller than expected number of student participants in the workshop.

**Objective:** Enhance the undergraduate research experience at SUNY Brockport and maintain the ACS-certified chemistry program based on the following learning outcomes:

- a) sound knowledge base relevant to the chemistry profession;
- b) lab and professional experiences relevant to the profession;
- c) well-developed critical thinking/problem solving skills;
- d) ability for students to construct their own understanding; and well-developed scientific communication skills which are all aligned with the National Science Education Standards (NRC, 1996).

**Evaluation Results:**

- The chemistry faculty members noted that the acquisition of the new NMR instrument resulted in additional grant funding that allowed for more students to have significant undergraduate chemistry research experiences than in years prior. They attributed the increased grant activity to the fact that the new NMR greatly expanded the ability of faculty to conduct research projects and to involve undergraduates in the research endeavor. The PIs noted that approximately half of the

undergraduate chemistry majors in the department work on special research projects involving the new NMR instrument to some degree.

- Chemistry faculty described how much more favorable the undergraduate research experience is now that the new NMR is in place. They noted that prior to this CCLI grant, students considered undergraduate chemistry research involving NMR to be “painful” and “dreadful.” They were referring to the excessive wait time associated with repairs being made to the instrument and the limited capacity of the old instrument to perform more sophisticated types of experiments. The new NMR instrument has an auto-sampler that enables students to set up their experiments to be run at a later time and enables them to access their data from remote locations using the same software, whereas the old instrument did not.
- Related to SUNY Brockport’s ACS certification, the chemistry faculty members contend that the new NMR allows the chemistry students to graduate with far more hand-on experiences using the instrument in various applications. The students now use the instrument in an entire series of undergraduate chemistry courses as they continually build their knowledge and experience base in NMR techniques. In the past, the old NMR was so unreliable that it was only used sparingly in a small number of courses meaning students had little exposure to the power of the device as an analytical tool in chemistry. Thus, students are now graduating from SUNY Brockport with more advanced preparation in the field of chemistry giving them a greater chance for future success in the field while they build their list of credentials.
- We believe that the acquisition and presence of the new NMR was a significant factor in our success in obtaining an undergraduate research grant funded by the Merck Institute for Science Education (Merck/AAAS) involving collaboration between the chemistry and biology faculty and undergraduate students on campus. Thus, the NMR instrument has become a key factor in expanding collaborative research among science faculty across campus, as well as providing 12 undergraduate chemistry and biology majors the opportunity to participate in summer research projects. In addition to laboratory research, these students participate in a series of learning experiences on and off campus. These include guest lectures by research scientists and visits to research labs on other campuses around the state.

**Objective:** Expand the capacity of SUNY Brockport to attract NMR-fluent faculty candidates to Brockport and to directly enhance faculty PIs' research endeavors.

**Evaluation Results:**

- In terms of using the new NMR instrument as a recruiting tool to attract talented new chemistry faculty, the project PIs report that the first of the anticipated wave of faculty retirements occurred at the end of the 2006-2007 academic year, and we anticipate searching for his replacement within the next academic year. Plans are being made to actively recruit chemistry candidates who will be able to effectively incorporate the new NMR instrument into their teaching and research activities.
- The newly hired Chair of the Chemistry Department at SUNY Brockport is an organic chemist whose primary research involves extensive use of NMR techniques. The ability of the faculty to recruit this individual was significantly enhanced by the new NMR instrument as reported by the search committee chairperson.

**Objective:** Increase collaboration with local industries related to summer research opportunities for undergraduate students as a result of the new NMR instrument and associated research endeavors.

**Evaluation Results:**

- Collaboration with local industry continues to be a positive outcome associated with the project. The Project PI has now established a relationship with the Johnson & Johnson Corporation to run NMR samples for them on a fee-for-service basis. In return for guaranteed access to the instrument, the company provided SUNY Brockport with vibration dampers for the NMR magnet.
- Because Brockport has an auto sampler, they are able to run time-consuming experiments for the research partnership with Rochester Midland Corporation overnight and avoid interfering with the work done by faculty and students on campus during the day.
- The Rochester Midland Corporation has funded one or two undergraduate student researchers for the past two summer sessions to conduct NMR-related experiments that benefit both their corporation and SUNY Brockport faculty. In addition, the user-friendly nature of the new NMR has enabled science majors from other departments to have

opportunities for greater interdisciplinary research experiences. For example, the evaluators interviewed a student from the Biology Department who was using the new instrument as part of a collaborative research project between faculty members in chemistry and biology. He noted the value of learning various instrumental techniques in terms of advancing his research efforts, as well as his future career potential as a scientist.

- One of the PI's received funding from the Petroleum Research Fund of the American Chemical Society in support of a research sabbatical during the 2007-2008 academic year at the Friedrich Schiller University in Jena, Germany. The sabbatical marks the beginning of an anticipated long-term research collaboration where diffusion measurements on SUNY Brockport's new NMR instrument will be a centerpiece of the research methods used. The establishment of an international research student exchange with the Friedrich Schiller University in Jena is envisioned.

**Objective:** Disseminate project outcomes through articles in the Journal of Chemical Education and the Journal of College Science Teaching, conference papers, posting evaluation reports on the website of SUNY Brockport's chemistry department, and eventually creating an instructor's manual for NMR workshop course.

#### **Evaluation Results:**

- The project PIs have been actively working to disseminate the project outcomes to various audiences. The department's web site is being updated to include specific information about this project. In addition, one of the newly developed inquiry lab experiments was published in the Journal of Chemical Education. The reference for this publication is:

Woodworth, J., Terrance, J., & Hoffmann, M. (2006). Using nuclear magnetic resonance spectroscopy for measuring ternary phase diagrams. Journal of Chemical Education, 83 970,1065-1066.

Two additional manuscripts describing the nail polish remover analysis experiment in Analytical Chemistry and the NMR imaging experiment in Physical Chemistry have just been submitted to the Journal of Chemical Education (JCE).

- The Project PIs are preparing an interactive excel spread sheet for the recently introduced JCE's WebWare dissemination website. A "lessons learned" manuscript that would provide insight for other faculty into

how to successfully implement a project of this type within their own institution is also in the planning.

### **Evaluation of Student Outcomes**

The evaluators also conducted an analysis of student outcomes from this CCLI grant project in relationship to their understanding of the nature of science and the overall research process. This involved gathering pre-intervention survey and interview data from a sample of chemistry students enrolled in the core courses during the 2004-2005 academic year and again from a sample of students in these same courses during the 2006-2007 academic year. Because of the initial problems with the functioning of the NMR device and the delays in starting some of the curriculum revisions, it was not possible to conduct a carefully controlled experimental study of the impact of the new NMR device on student outcomes. However, the evaluators were able to perform some basic statistical tests to determine how equivalent groups of students performed on the measures prior to, and following, the acquisition of the new NMR device as an indicator of how student outcomes were affected. These data were supplemented with the student interview feedback reported on earlier in this document.

To gather information about students understanding of scientific research, the evaluators administered the Test of Understanding Science (TOUS) (Klopfer and Carrier, 1970) to students in the core chemistry courses at the end of the spring 2005 semester and to an equivalent group of students in these same courses during the spring 2007 semester. Assuming equal variance between the before-intervention chemistry students (N=84, administered in spring 2005) and the after-intervention chemistry students (N=80, administered in spring 2007) a two-tailed t-test was calculated on the mean student scores on the 13 TOUS indicator items deemed to be most relevant to the primary objectives of this grant project. The alpha level was set at .05 for this test. The null hypothesis for analysis purposes was that the mean student score on the 13 indicator items before the intervention would not significantly differ from the mean student score following the intervention. The probability of falsely rejecting the null hypothesis was 95%. In the first administration of the survey, 60% of the students correctly answered the 13 indicator questions. In the second administration of the survey, 62% of the students correctly answered the same items. At an alpha level of .05, there is no significant difference between the scores on the first and second survey administrations in spite of the slight improvement in student scores on the TOUS items.

Table 1  
T-test Results

Group	N	Mean	Std. Error	Std. Dev.	95% Confidence Interval	
0	84	7.75	.2094134	1.919306	7.33485	8.166515
1	80	8.0125	.1992817	1.78243	7.61584	8.40916
combined	164	7.878049	.1446798	1.852806	7.59236	8.163737
diff		-.2625				
		diff = mean(0) - mean(1)			t = -0.9064	
		H <sub>0</sub> : diff = 0			degrees of freedom = 162	
		H <sub>a</sub> : diff < 0				

H <sub>a</sub> : diff < 0 Pr(T < t) = 0.1830	H <sub>a</sub> : diff = 0 Pr(T = t) = 0.3661	H <sub>a</sub> : diff > 0 Pr(T > t) = 0.8170
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The evaluators also conducted an analysis of a sub-sample of these same students using pre-test and post-test data about their understanding of the nature of the scientific enterprise. At the conclusion of the spring 2005 and spring 2007 semesters, students enrolled in the organic, analytical, and physical chemistry courses completed the Views on the Nature of Science (VNOS) questionnaire. The completed questionnaires from spring 2005 gave the evaluators a set of baseline data to describe the students' understanding of the nature of science prior to implementation of the inquiry-based curriculum, and allowed for comparison with the questionnaires from spring 2007. The latter group of students had full access to the new Bruker NMR and the inquiry-based curriculum. The evaluators examined the growth of students' understanding of the nature of science and the scientific research process over the span of the project, using an analysis technique similar to that used by Khishfe and Lederman (2007) to create a profile of views on a similar questionnaire about the nature of science. They delineated the student responses as either *naive* or *informed* in terms of their understanding of the nature of science. In looking at the three most relevant questions from the VNOS questionnaire, the evaluators obtained a sense for the differences between the 2005 and 2007 students' understandings of nature of science and the scientific research process. The three questions analyzed cover accepted aspects of the nature of science as per the *National Science Education Standards* (NRC, 1996) and the *Benchmarks for Science Literacy* (AAAS, 1993). In general, these questions deal with the nature of scientific knowledge and science as a human endeavor; specifically, they inquire about the tentativeness of science, the role of creativity and imagination in science, the differences between science and other disciplines (religion and philosophy), and the nature of experiments.

Based on an analysis of the 2005 data, it's clear that many of the students held typical naïve views concerning scientific research and experimentation that are consistent with undergraduate students. In many cases, this naïve view can be linked to the limited experience students had with true inquiry investigations and using authentic data collected from their own experiments, which inhibited their understanding of how scientists go about their work. The 2007 questionnaire data provide many examples that show that the implementation of inquiry investigations within the chemistry curriculum has contributed to a positive change in the students understanding of the nature of the scientific enterprise. The evaluators have summarized their findings from the pre- and post- data in Table 2, where it is evident that the post-test student data show an increased understanding of the nature of science and the scientific research process.

**Table 2**  
**Categorization of students' responses on the VNOS instrument**

	Tentative	Experimentation (scientific methods)	Science versus other disciplines	Creative and imaginative
<b>Informed (2007 data)</b>	<ul style="list-style-type: none"> <li>▪ Science is learning about our environment by asking questions and then testing various hypotheses in order to come to a reasonable conclusion. This is then studied, reviewed, and tested again by others.</li> <li>▪ In science, hypotheses are always changing and improving.</li> </ul>	<ul style="list-style-type: none"> <li>▪ It involves a question that needs to be answered, observations, methods, results, and conclusions, but not necessarily in that order. Not all sciences need to follow the same outlines.</li> <li>▪ Science is the collection, categorization, and interpretation of data about the physical world.</li> <li>▪ Process by which a scientist tries to reproduce physical phenomena in a controlled environment.</li> </ul>	<ul style="list-style-type: none"> <li>▪ The logic and reasoning required in scientific inquiry require facts and evidence.</li> <li>▪ Science relies on physical evidence and explanations [whereas] philosophy...relies on reason [and] religion...relies on tradition or supernatural revelation.</li> <li>▪ Religion and philosophy are opinionated and based on faith, which cannot be proven.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Science is very logical, yet at the same time, all scientists need to have a great semblance of creativity and imagination. [Science] tries to take the very essence of what life is, or the world is, break it down and understand it.</li> <li>▪ ...using different techniques and equipment to test a hypothesis.</li> <li>▪ Science is a mindful approach to solving problems, answering questions, and explaining how and why things happen.</li> </ul>
<b>Naive (2005 data)</b>	<ul style="list-style-type: none"> <li>▪ There is a precise method which relates all of the sciences or integrates them.</li> <li>▪ Science is concerned with factual, tangible evidence.</li> </ul>	<ul style="list-style-type: none"> <li>▪ An event of proving a hypothesis right or wrong.</li> <li>▪ A standardized method to answer or observe a question.</li> <li>▪ A test done on something to find out the details of what is being studied.</li> <li>▪ A step-by-step performance used to prove or disprove a theory or hypothesis.</li> <li>▪ Some experiments work and some don't.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Science...gives the best understanding of our world.</li> <li>▪ Science is all about calculations, precision, accuracy, estimates, assumptions, and results. Other disciplines are about memorization.</li> </ul>	<ul style="list-style-type: none"> <li>▪ Science is the study of relevant and irrelevant things to help us give meaning to life.</li> <li>▪ Science is not supposed to involve emotion, but investigation of theories and things that can be proved. You can't prove or disprove things based on emotion.</li> <li>▪ Science is quantitative.</li> </ul>

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## Appendix 1 Data Collection Instruments

# SUNY Brockport NSF Grant Evaluation

### Faculty Post-Project Interview Spring 2007

How would you describe the current chemistry lab curriculum at SUNY Brockport in the organic, analytical and physical chemistry courses?

How have the lab experiments changed as a result of the new NMR instrument?

In what ways, if any, have your teaching methods changed as a result of having the NMR?

Has having the NMR helped to actively engage students in the learning process and develop critical thinking and problem-solving skills?

What were the outcomes of the two-week NMR workshop in terms of both student outcomes and faculty outcomes?

How would you describe the undergraduate research opportunities for students at Brockport now that they have access to the NMR?

How has the new NMR instrument enhanced Brockport's efforts to achieve the learning outcomes associated with an American Chemical Society-certified chemistry program?

What is the status of the collaborative project with the Dept of Education and Human Services involving Peer-Led Team Learning in chemistry? How has the new NMR impacted your efforts?

What guided inquiry and project-based research experiments have been incorporated into the curriculum as a result of the new NMR? Who has been responsible for the development of these inquiry lab experiments?

How do you think students' attitudes and knowledge about chemistry research and the nature of science changed?

How have the chemistry faculty at SUNY Brockport benefited from having the new NMR instrument?

How has the overall SUNY Brockport campus benefited from this grant initiative?

How has the NMR enhanced collaboration with local industries?

In what ways are you disseminating the results of this grant project?

# SUNY Brockport NSF Grant Evaluation

## Student Post-Project Interview Spring 2007

How would you describe your lab curriculum in the chemistry courses now that the new NMR is here?

How have they changed since before the NMR arrived? Can you offer some specific examples?

How would you describe the teaching practices used in lab by your chemistry professors? Has the NMR impacted the way they now teach?

The grant calls for active engagement of students in the learning process and the importance of students developing critical thinking and problem-solving skills. To what extent has the new NMR facilitated this?

Describe what it means to do research in chemistry.

Did you participate in the two-week NMR workshop? Describe your experience in the workshop.

How have the undergraduate research experiences for students at Brockport been impacted by the NMR?

How has the new NMR instrument enhanced Brockport's efforts to achieve the learning outcomes associated with an American Chemical Society-certified chemistry program?

Have you had opportunities to work with the Dept of Education students in the Peer-Led team learning efforts? Has the NMR played a part in this?

How would you describe your general attitudes toward your chemistry experience at Brockport? Has the new NMR played a role in your attitudes?

