GUIDELINES FOR PREPARING A RESEARCH REPORT

Research experience is as close to a professional problem-solving activity as anything in the curriculum. It provides exposure to research methodology and an opportunity to work closely with a faculty advisor. It usually requires the use of advanced concepts, a variety of experimental techniques, and state-of-the-art instrumentation. Ideally, undergraduate research should focus on a well-defined project that stands a reasonable chance of completion in the time available. A literature survey alone is not a satisfactory research project. Neither is repetition of established procedures.

Research is genuine exploration of the unknown that leads to new knowledge which often warrants publication. But whether or not the results of a research project are publishable, the project should be communicated in the form of a research report written by the student. It is important to realize that science depends on precise transmission of facts and ideas. Preparation of a comprehensive written research report is an essential part of a valid research experience, and the student should be aware of this requirement at the outset of the project. Interim reports may also be required, usually at the termination of the quarter or semester. Sufficient time should be allowed for satisfactory completion of reports, taking into account that initial drafts should be critiqued by the faculty advisor and corrected by the student at each stage.

Guidelines on how to prepare a professional-style research report are not routinely available. For this reason, the following information on report writing and format is provided to be helpful to undergraduate researchers and to faculty advisors.

Organization of the Research Report

Most scientific research reports, irrespective of the field, parallel the method of scientific reasoning. That is: the problem is defined, a hypothesis is created, experiments are devised to test the hypothesis, experiments are conducted, and conclusions are drawn. This framework is consistent with the following organization of a research report:

Title
Abstract
Introduction
Experimental Details or Theoretical Analysis
Results
Discussion
Conclusions and Summary
References
**Title and Title Page**

The title should reflect the content and emphasis of the project described in the report. It should be as short as possible and include essential key words.

The author's name (e.g., Mary B. Chung) should follow the title on a separate line, followed by the author's affiliation (e.g., Department of Chemistry, Central State College, Central, AR 76123), the date, and possibly the origin of the report (e.g., In partial fulfillment of a Senior Thesis Project under the supervision of Professor Danielle F. Green, June, 1997).

All of the above could appear on a single cover page. Acknowledgments and a table of contents can be added as preface pages if desired.

**Abstract**

The abstract should, in the briefest terms possible, describe the topic, the scope, the principal findings, and the conclusions. It should be written last to reflect accurately the content of the report. The length of abstracts vary but seldom exceed 200 words.

A primary objective of an abstract is to communicate to the reader the essence of the paper. The reader will then be the judge of whether to read the full report or not. Were the report to appear in the primary literature, the abstract would serve as a key source of indexing terms and key words to be used in information retrieval. Author abstracts are often published verbatim in *Chemical Abstracts*.

**Introduction**

"A good introduction is a clear statement of the problem or project and why you are studying it." *(The ACS Style Guide. American Chemical Society, Washington, DC, 1986.)*

The nature of the problem and why it is of interest should be conveyed in the opening paragraphs. This section should describe clearly but briefly the background information on the problem, what has been done before (with proper literature citations), and the objectives of the current project. A clear relationship between the current project and the scope and limitations of earlier work should be made so that the reasons for the project and the approach used will be understood.

**Experimental Details or Theoretical Analysis**

This section should describe what was actually done. It is a succinct exposition of the laboratory notebook, describing procedures, techniques, instrumentation, special precautions, and so on. It should be sufficiently detailed that other experienced researchers would be able to repeat the work and obtain comparable results.

In theoretical reports, this section would include sufficient theoretical or mathematical analysis to enable derivations and numerical results to be checked. Computer programs from the public domain should be cited. New computer programs should be described in outline form.
If the experimental section is lengthy and detailed, as in synthetic work, it can be placed at the end of the report or as an appendix so that it does not interrupt the conceptual flow of the report. Its placement will depend on the nature of the project and the discretion of the writer.

**Results**

In this section, relevant data, observations, and findings are summarized. Tabulation of data, equations, charts, and figures can be used effectively to present results clearly and concisely. Schemes to show reaction sequences may be used here or elsewhere in the report.

**Discussion**

The crux of the report is the analysis and interpretation of the results. What do the results mean? How do they relate to the objectives of the project? To what extent have they resolved the problem? Because the "Results" and "Discussion" sections are interrelated, they can often be combined as one section.

**Conclusions and Summary**

A separate section outlining the main conclusions of the project is appropriate if conclusions have not already been stated in the "Discussion" section. Directions for future work are also suitably expressed here.

A lengthy report, or one in which the findings are complex, usually benefits from a paragraph summarizing the main features of the report - the objectives, the findings, and the conclusions.

The last paragraph of text in manuscripts prepared for publication is customarily dedicated to acknowledgments. However, there is no rule about this, and research reports or senior theses frequently place acknowledgments following the title page.

**References**

Literature references should be collated at the end of the report and cited in one of the formats described in *The ACS Style Guide* or standard journals. Do not mix formats. All references should be checked against the original literature.

**Preparing the Manuscript**

The personal computer and word processing have made manuscript preparation and revision a great deal easier than it used to be. Students should have the opportunity to use a word processor and have access to graphics software which allows numerical data to be graphed, chemical structures to be drawn, and mathematical equations to be represented. These are essential tools of the technical writer. All manuscripts should routinely be checked for spelling (spell check programs are helpful), and all manuscripts should be carefully proofread before being submitted. Preliminary drafts should be edited by the faculty advisor before the report is presented in final form.
Two Useful Texts


This book describes among other things the reasons for note keeping, organizing and writing the notebook with examples, and provides photographs from laboratory notebooks of famous scientists.


This volume is an invaluable writer's handbook in the field of chemistry. It contains a wealth of data on preparing any type of scientific report and is useful for both students and professional chemists. Every research laboratory should have a copy, and it should be as accessible as the *Handbook of Chemistry and Physics*. It gives pointers on the organization of a scientific paper, correct grammar and style, and accepted formats in citing chemical names, chemical symbols, units, and references.

There are useful suggestions on constructing tables, preparing illustrations, using different type faces and type sizes, and giving oral presentations. In addition, there is a brief overview of the chemical literature, the way in which it is organized and how information is disseminated and retrieved. A list of other excellent guides to technical writing is also provided. See also **The Basics or Technical Communicating**, Cain, B. E.; *ACS Professional Reference Book American Chemical Society: Washington, DC, 1988*.

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UNDERGRADUATE RESEARCH ACS-CPT SUPPLEMENT

Research can be the most rewarding aspect of an undergraduate chemistry degree. Students grow both professionally and personally in ways that are not possible through traditional classroom and laboratory classes. In addition, faculty members and chemistry programs are strengthened through the existence of student-faculty collaborative research. Since research unifies and extends the ACS-approved core chemistry curriculum, the Committee on Professional Training strongly encourages making research available to undergraduates as an advanced course option.

Student Benefits

Through undergraduate research, students develop problem-solving skills in a fashion that no other educational experience can match. The research experience requires that students reach beyond their classroom textbooks and use the chemical literature to learn about their research topic. Students learn to design their own experiments and make observations where the outcome is not already known. Their formal education gains added relevance when they apply classroom knowledge and laboratory skills in a research setting. Extensive hands-on use of research-quality equipment further develops their experimental skills and techniques. Students learn how to interpret results and draw conclusions from their own experiments. Finally, preparing both oral and written presentations of their research work completes the cycle of science by illustrating how their contribution to the scientific knowledgebase permits other scientists to build upon their efforts.

In addition to learning useful scientific skills, students involved in research develop personal traits that are critical for success in their future profession, be it in science or elsewhere. Research encourages students to develop a spirit of open inquiry and stimulates their personal creativity. Research students gain confidence to work independently and make sound judgments, yet they learn to ask for guidance when appropriate. The necessity of developing new approaches to failed experiments develops persistence and a strong work ethic, and the necessity of repeating successful experiments before publication causes students to recognize the importance of producing work of the highest standard.

Because research often occurs in teams, students learn to interact with their peers in a collaborative setting. They also learn to work with their mentors and interact with other faculty in a professional manner. By doing original science and working with established scientists, research students learn what it means to be a scientist. Furthermore, students become more employable by being involved in research. Potential employers greatly value the skills that are developed through research and actively seek students with research experience.

Faculty and Program Benefits

An undergraduate research program is valuable for the participating faculty as well as the students. Research activity is the most effective means of keeping faculty up-to-date in their field. Research invigorates the faculty intellectually, which leads to increased enthusiasm, better
morale, and improved teaching. Research activity emphasizes that science is not static. This encourages the faculty to change and improve their course offerings.

Undergraduate research also produces programmatic benefits to chemistry departments. External funding for research brings new equipment and facilities into the department. It is especially effective when equipment can be used in both research and teaching, so that all students receive the benefit of research-quality instrumentation. An active research program is also a key element in attracting the most talented individuals to join a faculty, which directly strengthens the overall program.

Required Institutional Commitment

A successful undergraduate research program requires a committed faculty, supportive administration policies, and appropriate resources. First, the department faculty must view research as an essential aspect of their program. Measures of commitment include the writing of research proposals and the publication of research results. Second, the institution must recognize that the tremendous benefits of undergraduate research cannot occur without significant faculty effort. In successful undergraduate research programs, the administration recognizes undergraduate research as a valid method of teaching and gives some form of credit to faculty for their undergraduate research activities, usually through teaching commitments that recognize research involvement. Third, the program must have both adequate financial resources and appropriate space in which to carry out research. Funds should be available for supplies and stipends, matching of equipment grants, faculty and student travel to professional meetings, and sabbatical leaves for scholarly growth. Dedicated facilities for research that meet all safety guidelines must exist. Finally, the Committee on Professional Training notes that extensive use of part-time or non-tenure track teaching faculty by an institution reduces the fraction of research-active faculty and the number of research opportunities for students.

Characteristics of Undergraduate Research

Research is the development of new knowledge or understanding in order to advance science. While the specific areas of research vary immensely in the chemical sciences and in chemical education, there are some traits that are common to undergraduate research in general.

Undergraduate research is conducted with a faculty advisor or mentor. The student’s research project is typically based on the faculty mentor’s research interests, which allows the student to draw upon the mentor’s expertise and resources and also allows the faculty mentor to develop a productive research program. The mentor meets regularly with the student to make research plans, assess risks associated with the proposed research, and review results. The student is encouraged to take primary responsibility for the project and to make substantial input into its direction. The student-mentor relationship also builds student confidence, offers encouragement when necessary, and provides guidance and assistance for the student’s future education and career development.

Undergraduate research should be envisioned as publishable in a peer-reviewed journal. Research builds upon the previous accomplishments of other scholars. For research to have any
meaning or effect, it must be communicated to the scientific community. Peer-review is the generally accepted means of monitoring and insuring the quality of research. While not every undergraduate research project will result in a peer-reviewed publication, it should be the intent of each project to contribute to such a result. When an individual student research project is not of wide enough scope for an entire publication, it can often be combined with other undergraduate research projects into a more comprehensive study that merits publication.

While the nature of each project depends on the specifics of the project, an ideal undergraduate research project:
- has a clearly-communicated purpose and potential outcomes
- has well-defined objectives and methods
- is substantial in scope (as opposed to a collection of small projects)
- has reasonable chance of completion in available time
- requires contact with the chemical literature
- avoids repetitive work
- requires use of advanced concepts
- requires a variety of techniques and instruments (not exclusively library work)

Finally, undergraduate research should culminate in a comprehensive written report. Oral and poster presentations are an extremely useful step in this process. However, a research project should not culminate solely in an oral presentation, as it would not become part of the archived body of knowledge. A written report adds to the permanent scientific knowledgebase and can be used by future subsequent researchers pursuing related projects.

Research in the Guidelines

The Committee on Professional Training highly recommends that research be part of the education of an ACS-certified chemistry degree. Research may be used for some or all of the six semester hours of advanced courses required for ACS certification. Research may also be used for some or all of the advanced laboratory hours needed to reach a total of 500 laboratory hours.

If research is used for an advanced course or advanced laboratory hours, then a well-written, comprehensive, and well-documented research report must be prepared. The faculty supervisor should constructively criticize drafts of the report. A separate supplement provides guidelines for preparing a research report. Oral, poster, and/or computer presentations do not meet this requirement. Student coauthorship on a paper, while highly encouraged, is not a substitute for a comprehensive report written by the student. Examples of student research reports must be included with an institution’s five-year report if research is used as an advanced course for student certification.

Research done off-campus and/or during the summer, even though it might not be for academic credit, may count toward certification. In such cases, the student must prepare a comprehensive report that is evaluated and approved by a faculty member of the home institution.