The Essential Features of Undergraduate Research

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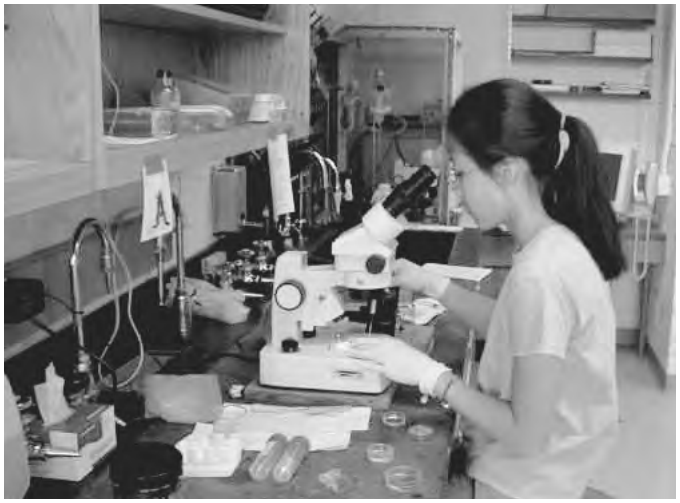
A few years ago principal investigators representing RAIRE/AIRE (Recognition Award for the Integration of Research and Education/Award for the Integration of Research and Education) institutions attended a meeting at the National Science Foundation (NSF) in Washington, DC. During a discussion about assessing the impact of undergraduate research on learning, Elaine Seymour of the University of Colorado suggested that science faculty be asked their opinions on two fundamental questions:

- What are the essential features of a successful undergraduate research experience? and
- What are the benefits of a successful undergraduate research experience?

The goal of this informal inquiry was to create a starting point for a more precise assessment of the outcomes of doing undergraduate research. Following the meeting, several of the participants undertook a poll of interested faculty at their home institutions. I volunteered to receive the results. Based on the efforts of Karen Yoshino at Harvey Mudd College, Mary Allen at Wellesley, and myself at Grinnell College, we were able pull together the opinions of faculty from three institutions. I have summarized these opinions on several occasions, presenting information at meetings of the Council on Undergraduate Research and Project Kaleidoscope. During the summer of 2001, I was able to supplement these faculty views by surveying undergraduate research students who were working in summer research programs at Grinnell, Harvey Mudd, Hope and Wellesley. The research has given me the opportunity to learn what features and benefits faculty believe are essential to the undergraduate research experience and to decide if students share these views.

My summary of the faculty responses to the two questions is found in Tables 1 and 2. Twelve faculty members from Harvey Mudd, fourteen from Wellesley and fifteen from Grinnell volunteered answers. Some respondents made many suggestions, and there was overlap among the data from the three institutions.



Grinnell student Jane Chang conducts a study of nicotinic acetylcholine receptors in the laboratory of chemistry professor Mark Levandoski.

Faculty Responses: Essential Features

Tables 1 and 2 are arranged to show a composite of the responses from faculty at the three institutions. Table 1 shows the essential features of undergraduate research: They should prepare by reading relevant literature. They should have the support of a mentor and a learning community. They should have the opportunity to design the research, and they should experience working independently. When the work is completed they should have an opportunity for professional quality communication.

These responses may seem so familiar to an experienced mentor of undergraduate researchers that there is no need for a second look. I suggest, however, that Table 1 contains at least two sorts of items, those that may be called *structure* items and those that may be called *consideration* items. Structure and consideration are terms I borrow from the literature on leadership in organizational psychology (Muchinsky, 1990). According to the leadership theory of Fredrick Fiedler, a leader can be successful by attending to structure and consideration. By structure items, I mean those features of undergraduate research that contribute to the structure of the research problem or process. Research on classroom leadership has shown that structure includes course content and learning tasks (Lahat-Mandelbaum & Kipnis, 1973), as well as the clarity of the learning objectives, the use of class time, and the instructor's preparation (Baba & Ace, 1989). Structure items for undergraduate research may include the facilities and equipment, assignment of tasks, scheduling, provision of primary literature and outcome requirements such as posters and papers. These items may be prepared or scheduled. Consideration items are difficult to schedule.

Table 1. Faculty responses to the question "What are the essential features of undergraduate research projects"? Items are a composite of responses from three institutions. Numbers at the right indicate how many of the institutions explicitly mentioned the item.

Students should read scientific literature.	**3**
Students should design some aspect of the project; students should have an opportunity to design and conduct the research; opportunities should exist for exploration of the student's ingenuity and creativity.	**3**
Students should work independently (of faculty) and have an opportunity to work on a team (of peers); establish a mentoring partnership between student and faculty.	**3**
Students should feel ownership of the project; there should be increased independence in the daily routine and problem solving.	**3**
Students should use careful and reproducible lab techniques; there should be a mastery of the techniques necessary to the research.	**3**
Students should have an opportunity for oral communication.	**3**
Students should have an opportunity for written communication.	**3**
Students should have a meaningful or focused research question.	**2**
Faculty should provide some structure to the experience.	**2**
Students should strive to produce a significant finding.	**1**
There should be a good (state-of-the-art) environment.	**1**
Students should have an opportunity for attendance at professional meetings.	**1**
Students should earn pay or credit.	**1**

By consideration items, I mean those features of mentor behavior that contribute to the emotional and social needs of the student. In the classroom, consideration by the instructor includes being available for consultations, acting helpful and concerned, and being open to students' views. These are personal or interpersonal features of undergraduate research. They rely on the expertise of the faculty mentor as a teacher and researcher. Consideration items for undergraduate research may include establishing a balance of supervision and independence, developing a continuing relationship, and showing concern for a student's needs, and are features of the undergraduate research experience that a mentor may strive for but be unable to program or schedule into the experience.

Faculty Responses: Benefits

The faculty's list of benefits resulting from the undergraduate experience (Table 2) dovetail with the list of essential features. Opportunities to work and think independently, to read literature and to communicate are thought to result in learning in these areas. In addition, direct experience with a research question leads to an increment in research and problem-solving skills. Finally, the milieu leads to an appreciation of what scientists do. As with the essential features, the benefits may be viewed as resulting from structure or consideration. Some structural essential features and their corresponding benefits are difficult to distinguish. Learning to read scientific literature implies having this activity scheduled. Improving skills in communication follows from preparing for and doing scheduled talks and papers. The relation between consideration items and the resultant personal development is more difficult to discern. What features of undergraduate research enable such benefits as "Appreciate what scientists do" or "Find a faculty mentor for continuing relationships?" It may be the interpersonal features that I call consideration that enable these benefits.

It can be difficult to assess the association between the essential features and the resulting benefits of undergraduate research. Nevertheless, the faculty responses provide a starting point. If essential features of undergraduate research are put into practice, the benefits may be acknowledged by participating students. The convergence of faculty intentions and student responses may yield valuable information for the assessment of the undergraduate research experience.

Student Responses

Recently I was able to follow up on the earlier AIRE-funded research with a survey of 249 students working in summer undergraduate research programs at four institutions: Grinnell College, Harvey Mudd College, Hope College and Wellesley College. The students participated in similar summer programs for undergraduate research. They represented biology,

chemistry, computer science, engineering, mathematics, physics and psychology. These students were asked to select the most important benefits of undergraduate research experience from a list of 45 items. The items were generated from the faculty items as well as benefits suggested in the literature on undergraduate research. Each student read the list and chose five items they thought were particularly important. The ten most frequently chosen items are listed in Table 3. (If we leave aside the data from Hope College, for which we do not have faculty input for comparison, the items in Table 3 shift slightly with respect to their standing. These ten items, however, remain the top ten).

The first two items are career-oriented benefits: "Enhancement of professional or academic credentials" and "Clarification of a career path." The other seven items are variously cognitive, behavioral and social. Comparing the items in Table 3 with those in Table 2, we can see an overlap between the benefits faculty view as important and the benefits the students view as important. Both faculty and students mentioned career plans, learning in depth, research and laboratory skills, and developing relationships. There is some divergence between faculty and student views, however. Faculty respondents at all three institutions listed learning about communication as a benefit of undergraduate research experience. Communication would seem to be important to faculty. The first reference to communication skills on the student list of benefits is ranked 26th out of 45: "skill at oral communication." Skill at written communication is ranked 36th, and skill at visual communication is ranked last. Faculty respondents valued reading relevant literature or literature reviews. The student data reveal that the highest ranking benefit regarding reading, "ability to read and understand primary literature," is a modest 22nd on the list of 45 benefits, while "ability to locate and identify relevant literature" stands at 32nd and "critical evaluation of hypotheses and methods in the literature" ranks 43rd.

Faculty and students seemed to agree that some benefits are, relatively speaking, not important. The faculty did not explicitly refer to either learning ethical standards or learning safety techniques (although these may be implied). For the students, learning about ethical standards ranks 41st out of 45 items; learning about safety techniques ranks 44th.

What do the convergence or divergence of faculty and student opinions tell us about the undergraduate research experience? The faculty responses are a mix of structure and consideration items, but it is the consideration items that rank high on the student list. I suggest a hypothesis: Students value consideration more than structure. The benefits they value result from a good relationship with and expert guidance from a mentor. They learn from the mentor how scientists think, how obstacles are tolerated and how a career path develops. The behavior of the mentor may affect them more than the state of the physical facility or the poster requirement as the project ends. The hypothesis may help explain why smaller institutions (such as my own liberal arts college), which claim to provide more faculty-student contact, may produce a high proportion of graduate students in the sciences despite having smaller and less impressive facilities than research universities (Cech, 1999). The hypothesis suggests that broadest level of structure of an undergraduate research program, such facilities, state-of-the-art equipment, and programmed poster sessions, may fail to yield desired responses from undergraduate researchers without a concomitant attempt to develop the art of considerate mentoring in science faculty.

Table 2. Faculty responses to the question "What are the benefits that students gain as a result of doing undergraduate research projects"? Items are a composite of responses from three institutions. Numbers at the right indicate how many of the institutions explicitly mentioned the item.

Learn a topic area in depth; have intensive exposure; learn subject matter in detail.	**3**
Construct meaningful problem; apply knowledge to a real situation.	**3**
Learn to use appropriate methodology; develop proficiency in laboratory practice and techniques.	**3**
Learn to work and think independently; foster independence.	**3**
Learn to design solutions to problems; learn to analyze data.	**3**
Improve oral communication skills.	**3**
Improve written communication skills.	**3**
Appreciate what scientists do; learn what scientific research actually entails.	**3**
Develop an orientation toward future work and education; clarify career plans.	**3**
Learn to use scientific literature.	**2**
Gain experience with contributions to a body of knowledge; learn how research ideas build on preceding studies.	**2**
Make connections to what was learned in courses.	**1**
Find a faculty mentor for continuing relationships.	**1**

Table 3. Student responses to the instruction to select the five most important benefits of an undergraduate research experience. Students selected from a list of 45 possible benefits. The 10 most frequent choices are listed in order from most frequent. 249 students took part in the survey.

Enhancement of professional or academic credentials.
Clarification of a career path.
Understanding the research process in your field.
Learning a topic in depth.
Developing a continuing relationship with a faculty member.
Learning to work independently.
Learning laboratory techniques.
Tolerance for obstacles faced in the research process.
Understanding how scientists think.
Understanding how professionals work on real problems.

This is not to say that structure does not count. Research on leadership indicates has shown that consideration and structure may interact (Butler & Cantrell, 1997). A considerate mentor may attempt to provide a specific level of structure that seems optimal for the student researcher. To paraphrase Fiedler (1987), a mentor may need to know when to structure and when to stand back. It may be that the present view is largely dependent on the context of the four-year undergraduate institutions that provided the data - but I do not think so. CUR workshops on assessment at larger institutions at the 2002 National Conference referred to faculty surveys with similar results (e.g. Zydney, Bennett, Shahid, & Bauer, 2002). The continuing study of the essential features and benefits of undergraduate research experiences will continue to support the view that faculty mentors provide the essential structure and consideration that foster competence, independence and maturity in the student. In this broad sense, "Research with undergraduate students is in itself the purest form of teaching" (Gentile, 2000).

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Grinnell students perform biology experiments.

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