students with a strong interest and proven skill to undertake undergraduate research; MIT, working from a more select group, associates these projects very closely to on-going graduate research projects; and WPI where all students, individually or in groups, take part in a research experience.

As one can see, undergraduate research means different things to different people. In order to try and address whether undergraduate research is indeed a reality or a myth, I feel that we should have a working definition of research. Borrowing, in part, from Webster's New International Dictionary, Second Unabridged Edition, research is defined in the following manner:

> "RESEARCH—*Studious* inquiry or examination: *specific* and usually, *critical* and *exhaustive investigation* or *experimentation* having for its *aim* the *discovery* of *new facts* and *their correct interpretation*; the revision of accepted conclusion, theories, or laws, in the light of newly developed facts, or the *practical application of such new or revised conclusion*, etc. . . ."

The words I consider to be key words are italicized.

Any project that adheres to this definition is certainly publishable. I further restrict our definition to include the statement that if the undergraduate project is of a research nature it has been, or shortly will be, published in a refereed publication. With these definitions and restrictions in mind, the following questions were asked informally of 20 faculty members at WPI and approximately five faculty at five other universities.

- **How many undergraduate research projects done by a single undergraduate result in a publication in a refereed journal?**
- **How many undergraduate research projects done by a group of undergraduates result in a publication in a refereed journal?**
- **If the project is done as a part of an on-going research effort, how often does this project result in a publication? Part of a publication?**
- **If an undergraduate project is continued from year to year, how often does this lead to publication?**
- **How valuable is undergraduate research?**

The answers I received can be summarized as follows: Typically, whether done individually or in groups, undergraduate research projects result in fewer than 15% being published in refereed journals. If the project is associated with an existing research program, the number published increases to approximately 30-40%. However, this increase does not reflect an increase in publications for individual projects. It does reflect the fact that parts of the undergraduate project will be included in publications associated with this research. The number of publications was perceived to increase for projects that were continued or on-going. However, this increase was thought to be minimal. Finally, all faculty felt the undergraduate involvement in research was an excellent learning experience.

Obviously, the sample of faculty informally polled is too small for definitive conclusions to be drawn. I do believe, however, that the answers received reflect general trends. The answers reflect my own experience, which is that undergraduate research projects are seriously constrained by time and, unless attached to an on-going graduate research project, money. The need for well defined manageable undergraduate projects is, in my opinion, reflected in the increased publication rate for projects being part of a larger, well defined effort. The results of my informal survey suggest that based on the stated criteria, undergraduate research is more myth than reality. Admittedly, the criteria were restrictive and the sample small; but, perhaps the real value in undergraduate research lies not in the research itself, but in the knowledge and experience gained in the search for understanding. □

UNIVERSITY OF MAINE

UNDERGRADUATE RESEARCH: A Necessary Education Option And Its Costs And Benefits

ARTHUR L. FRICKE
University of Maine
Orono, ME 04469

CHEMICAL ENGINEERING IS A practice rather than a science. Even though the principles of science are applied to solve engineering problems, it is seldom that the final solution can be predicted from first principles with sufficient confidence to eliminate all need for demonstration. More often, the problem requires at least demonstration and frequently experimental study of elements of the process or experimental determination of needed physical data. Ideally, chemical engineering students should not only be required to take experimental as well as theoretical courses, but should also be given the opportunity to exercise *judgment* in deciding when experimental work

is required and the opportunity to *demonstrate* that their solution works.

Undergraduate research is one means that can be used for practice in judgment and demonstration, and it can be considered a necessary option for this reason. Undergraduate research offers other benefits to the student. By its very nature, undergraduate research involves independent study and exposes the student to self education. It also assists the student in making career decisions and often provides opportunities to learn how to interface effectively with other engineers and scientists.

Undergraduate research also provides benefits to the faculty and to the institution. Research by undergraduates can be original and significant; it strengthens faculty-student interaction and is a good way for the faculty to evaluate their teaching effectiveness. Undergraduate research can benefit the institution by improving the primary product (the graduates) upon which an institution's reputation is based.

If there are all of these benefits, why isn't undergraduate research encouraged more? The answer lies in costs. Research requires time, materials, capital, and space. All of these are severely limited resources in today's university. The amounts that can be allocated to a single student research project (typically 3 student credit hours or SCH) from the university budget at the University of Maine are shown in Table 1. Only 6.2 hours of faculty contact, \$14.28 of materials, \$35.00 in capital, and 60 square feet of space can be allocated to a project. Obviously, with these meager resources the project is doomed before it begins.

Arthur L. Fricke has been chairman of ChE at the University of Maine since 1976. He received his ChE degree from the University of Cincinnati in 1957 and his M.S. and Ph.D. from the University of Wisconsin in 1959 and 1967. He has had considerable industrial experience and has been teaching since 1967. His current research interests are in polymer processing and pulping recovery systems.

Undergraduate research . . . is often not available because of the limited resources available and because of the view of faculty that directing undergraduate research is personally unrewarding.

TABLE 1
Limited Resources in Undergraduate Research

FACULTY TIME:
Avg. Load = 300 SCH/FTE/SEM. at
3 cr. hr./Res. Proj./Stu.:
Time = (3/300) x 15.5 x 40 = 6.2 hrs!

MATERIALS:

$$\frac{\text{Supply Budg.}}{\text{SCH.}} \times \frac{\text{SCH.}}{\text{Res. Proj.}} = \frac{\$20{,}000}{4{,}200} \times 3 = \$14.28$$

CAPITAL:

$$\frac{\text{Capital Budg.}}{\text{Lab SCH.}} \times \frac{\text{SCH.}}{\text{Res. Proj.}} = \frac{\$10{,}000}{900} \times 3 = \$35.00$$

SPACE:

$$\frac{\text{Lab Space}}{\text{Lab SCH./Sem.}} \times \frac{\text{SCH.}}{\text{Res. Proj.}} = \frac{9{,}000}{450} \times 3 = 60 \text{ sq. ft.}$$

Success of an undergraduate research program depends upon proper management and enlargement of resources. Sources of supervisory time, financial support, and space that can be used are given in Table 2. The only real insoluble problem is space. Before any undergraduate research project is suggested to a student, the faculty member should have tapped these or other sources for resources required.

There are general requirements that must be met if an undergraduate research project is to be successful. The faculty must set a well defined objective with a good plan for necessary supervision; the faculty must be prepared to find the necessary materials and equipment; the student commitment to the work must be strong; and proper reporting of results and conclusions must be a part of the project. The last should be a clearly understood requirement from the beginning.

Some pertinent data on three examples of undergraduate research are given in Tables 3, 4, and 5. The Fiber Porosity project summarized in Table 3 is the traditional one-student project. The

TABLE 2

SOURCES OF SUPERVISORY TIME

1. Faculty
2. Graduate Students
3. Technicians
4. Industry

SOURCES OF FINANCIAL SUPPORT

1. Government
   - Undergraduate Research Participation
   - Research Grant Funds
   - Dept. of Education
2. Institution
   - Dept. Unrestricted Funds
   - Competitive Grants
3. Industry and Foundations
   - Competitive Grants
   - Restricted Gifts
   - "Service Development"

SOURCES OF SPACE

"?"

student was asked to modify the mercury porosimeter method for determining the porosity of fibers. The data were needed for a graduate research project, so supervision was provided principally by the graduate student. Since the equipment was available, only marginal costs and additional space were required. The small cost was paid from research grant funds. This project led to a successful modification of the method and results were obtained that were included in the research publication. Finally, these results were used as partial support for another research proposal.

Table 4 summarizes a group design and development project. Funds were obtained from the college and as a directed gift from industry to construct a new general purpose distillation column that could be controlled in real-time with our DEC 11/60 computer and used in our unit operations laboratory. The project cost (mostly for metal, prime movers, and control systems) was $34,000. The students and faculty designed all components of the system, prepared shop drawings, and supervised fabrication and construction. A 4-inch diameter x 30 plate column with reboiler, condenser, and storage was constructed of stainless steel and electronic analog control loops were installed. The students devised a complete plan for connecting all controls to the DEC 11/60 for supervisory operation or for DDC.

Table 5 summarizes a group research project on "Spruce Pulping" by the Kraft process. This work was part of a funded research project on the effects of spruce budworm kills on pulping of various species. The faculty time was high, but was principally paid for by the external sponsor. The project cost of $2400 ($600/student) was also charged to the external sponsor. With assistance and supervision the students designed their experiments, conducted the pulping experiments, made paper and conducted appropriate physical tests, and used statistical methods to analyze their results. Their work resulted in a reviewed publication. The industrial sponsor was very satisfied with their performance and this has led to a new and larger research grant.

We have reviewed the performance of well managed undergraduate research research projects. The summary of this experience, based upon work with 30 students, is presented in Table 6. It has been my experience that the largest feasible group is four students. Effective supervision can be provided by graduate students or technicians, *if* the project is well defined by the faculty. In general, the project must be zero cost or must be justified on another basis. Often,

TABLE 3
Fiber Porosity

1 Student @ 3 cr. hrs.	=	155 St. Hrs.
Faculty Time	=	5 Hrs.
Grad. Stud. Time	=	30 Hrs.
Tech. Time	=	4 Hrs.
COST	=	$50

RESULTS:

1. Modification of Method
2. Published Results
3. Support for Research Proposal

TABLE 4
Distillation Column

4 Students @ 3 cr. hrs. each	=	620 st. hrs.
Faculty Time	=	46.5 hrs.
Technician Time	=	250 hrs.
Capital	=	$27,000
Materials		7,000
Total Cost	=	$34,000

RESULTS:

1. St. Steel 4" Dia. x 30 Plate Column with reboiler, condenser, storage constructed
2. Electronic analog controls for feed (FIC, TI), bottoms (LC, FI, TI), Tops (LC, FI, TI), Reflux, (FIC), Steam (FIC, PIC), Cooling Water (TIC), and Temperature measurement (TI).
3. Plan for hook-up to Dec 11/34 for DDC control
4. New U.O. lab unit

we purposely submit research proposals in which part of the work is designed for undergraduate research and necessary funds for the undergraduate work are requested as an integral part of the proposal. Space is always a question, but it has always been available.

The tangible results of the work of these 30 students is impressive. In 80% of the cases, the objective was accomplished and the project was thus rated a "success." Approximately 50% of the students involved entered graduate school. Approximately 50% of the research results were publishable as an independent paper or as part of another research paper; 30% led to development of equipment for the department; and about 30% served to improve relations with industry due to the competence of the work. About 15% (4 to 5) led to research proposals that were granted. Finally, these projects led to substantial improvement in student/faculty relations. These results lead us to consider our program of undergraduate research to be a successful and worthwhile part of undergraduate education at the University of Maine.

TABLE 5
Spruce Pulping

4 Students @ 6 cr. hrs. each	=	1240 st. hrs.
Faculty Time	=	90 hrs.
Technician Time	=	185 hrs.

COSTS

Capital	=	$ 600
Materials	=	1,800
Total Cost	=	$2,400

RESULTS:

1. Reviewed Publication
2. Digester Performance Reviewed
3. Industrial Relation Established
4. Research Grant Obtained

TABLE 6
Experience Summary (30 Students)

PROJECT COST AND STAFFING

Students: 1 to 4 = 155 to 1240 hrs.
Faculty: 5 to 100 hrs.
Grad. Student: 0 to 50 hrs.
Technician: 0 to 300 hrs.
Materials: 0 to 7000
Capital: 0 to 27,000
Space: "?"

RESULTS

80% of Projects Successful
50% Students—Grad. School
50% — Publishable Results
30% — Dept. Development
30% — Industrial Relations Improvement
15% — Research Grants

IMPROVED STUDENT/FACULTY RELATIONS

Undergraduate research should be an option available to at least the more gifted students in all chemical engineering programs, but is often not available because of the limited resources available and because of the view of faculty that directing undergraduate research is personally unrewarding. *This need not be.* Resources can be expanded from outside sources by the department administration and the faculty to permit this option to be offered to a significant number of students. By properly managing their time and other supervisory time, faculty can direct undergraduate research so that it results in publications, improved experimental methods, and research proposals, all of which lead to personal rewards to the faculty. What *is* required is a consensus that undergraduate research is a desirable option and the willingness of faculty to participate in designing projects, collecting resources, and providing supervision. □

STATE UNIVERSITY OF NEW YORK AT BUFFALO

ChE UNDERGRADUATE RESEARCH PROJECTS IN BIOMEDICAL ENGINEERING

PIETER STROEVE
State University of New York at Buffalo
Amherst, NY 14260

THE UNDERGRADUATE PROGRAM IN chemical engineering at the State University of New York at Buffalo is highly structured. At present, the chemical engineering program is organized on the basis of four courses per semester with each course carrying four units of credit. Contact time is at least one hour per week per unit of credit. In the program most of the technical courses are specified through the junior year. Although the program is undergoing changes, technical electives are still chosen by the students in the senior year.

The Department of Chemical Engineering conducts an active undergraduate research pro-