lar ability for experimental work of a demanding nature and yet not be outstanding academically. Clearly, undergraduate research provides an opportunity to identify such students and to counsel them appropriately.

Motivating students to elect to take undergraduate research is essential. In addition to pointing out the merits of undergraduate independent study with respect to the undergraduate's imminent career decision, I use a goal-oriented approach in motivating them. In particular, I encourage them to undertake this research in order to compete in a particular local, regional or national technical papers competition. Competitions to keep in mind here are the technical papers contests for students sponsored by the student chapter of the AIChE, the Oklahoma Engineers' Club, the Colloid and Surface Chemistry Division of ACS, the American Institute of Aeronautics and Astronautics, as well as those of several other professional societies. Another motivating factor which helps the students persevere in completing their research is the commitment to publish their results in some form. One need not consider only peer-reviewed publications here. Indeed, only one of my 28 undergraduate research projects has led to a peer-reviewed paper. Consider publishing the results of a worthwhile undergraduate study in college or university student magazines. News releases to local as well as the students' hometown newspapers are also an excellent way to recognize the extra effort which an undergraduate research project requires. This publicity is also of value to our colleges and universities during these times of critical appraisal of higher education, particularly in tax-supported schools.

My final comments concern funding of undergraduate research. The NSF undergraduate research participation program is well known and is, of course, an excellent source of funds. However, I would encourage researchers to include some support for undergraduate assistants in their proposals to the funding agencies. In addition, some companies that are reluctant to support graduate research programs may well support an undergraduate research program if they recruit primarily at the B.S. level. Finally, I have encouraged both our student chapter of the AIChE and Omega Chi Epsilon, the chemical engineering honor fraternity, to consider as chapter projects underwriting some part of the cost incurred in having our undergraduates participate in technical papers competitions or present papers at technical meetings. In this way, all our chemical engineering students become aware of our undergraduate-research program and take pride in the achievements of the students participating in this program. □

NATIONAL TECHNICAL UNIVERSITY OF ATHENS

UNDERGRADUATE RESEARCH AS A PREREQUISITE FOR GRADUATION

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"THE SWEETEST AND MOST inoffensive path of life leads through the avenues of science and learning; and whoever can either remove any obstructions in this way or open up any new prospect ought so far to be esteemed a benefactor to mankind." In such a concise way David Hume expressed the unity of teaching and research back in 1748 [1]. A modern corollary of Hume's statement may be found in Rutherford Aris' warning that "the attempt to divorce teaching and research is fatal to the life of a university department" [2].

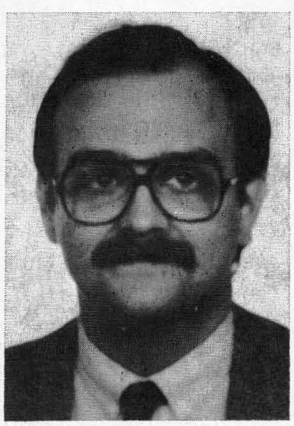
One can hardly resist the temptation to add: is this unity necessary even for undergraduate education? Based on the discussion which has recently started among chemical engineering educators in the United States [3], it seems that the possible contribution of undergraduate research to the curriculum is still questionable. Is it legitimate then to consider this revitalization of the interest in undergraduate research as a warning? The fact is that several professors, alarmed by some consequences of this separation of teaching from research, think of optional research activity as a remedy [4]. Are they right and to what extent?

In this paper we will try to give an answer to those questions not by an abstract approach, but by examining a different educational system, where undergraduate research is an organic part of the curriculum. This author spent several years in such an educational environment, at the School of Chemical Engineering of the National Technical University of Athens (or NTU), in Greece, first as a student and then as an instructor, having supervised a total of twenty-five undergraduates in the period 1976-1979. What follows is based on a critical account of this experience.

TWO MAJOR SYSTEMS

Historically, chemical engineering has been developed around two poles: Germany and the United States [5]. Many European countries organized their particular educational systems under the strong influence of the German model in such a way that today we can talk about a major European system [6, 7]. This system characterizes practically all chemical engineering departments in Western (with the exception of the Anglo-Saxon countries), Central, North, and South Europe, and even some in Eastern Europe, e.g. Poland [8].

A historical analysis of the chemical engineering curriculum at NTU shows that, since the mid-sixties, there has been a significant influence of the American model [9]. However, as in other European countries[6], the outcome is a hybrid that can still be classified under the label of "European approach." There are sides of the modern Greek system that, despite recent modifications, continue the German tradition. The extensive teaching of chemical technology is one example [10], and the required research for the preparation of a Diploma Thesis is another one.



The idea that modern chemical engineering should not neglect its economic and social implications has dominated first the studies (Dipl. ChE, Dr. Eng., Dipl. Econom., M.S. Regional Devel., all from NTU and other Greek Universities), and then the research and teaching (biomass, industrial processes, technology transfer) of **Emmanuel Koukios.** A second idea, that of a critical approach to Science and Art, is the focal point of his other interests (movie critique, epistemology, phychoanalysis, semiology). Currently on a leave of absence from NTU of Athens, he is Visiting Assistant Professor of Chemical Engineering at Purdue University.

TABLE 1
The Relative Position of Undergraduate Research in a European Chemical Engineering Curriculum (NTU)

SEMESTER	COURSES	RESEARCH STEPS
9th	Technical Electives	(1) Meetings with faculty; discussion of topics offered (2) Final assignment (3) Literature searching (4) Familiarization with methodology
10th	——	(5) Preliminary oral presentation of collected information and proposed plan of work (6) Full-time supervised research (7) Oral presentations in regular research meetings (8) Thesis writing (9) Thesis submission (10) Thesis presentation (11) Grading by a Committee composed of three faculty members
		(12) Continuation by another student; the previous one may be used as a consultant

Table 1 presents the main steps of the procedure which take place in the last two semesters, and lead to the submission and oral presentation of the Diploma Thesis. It is clear that one whole semester is available for research, while a significant part of the previous semester is used for the same purpose. Of course, it can be objected that due to the fact that the program lasts ten semesters, the preparation of the Diploma Thesis corresponds to the preparation of a M.S. Thesis, and therefore this work cannot be considered as undergraduate research. If we neglect, for the moment, the complicated problems of the official equivalence between the two major systems, it appears that, since this research is required for graduation, it belongs to the undergraduate and not the postgraduate stage.

Such a requirement cannot be found in the American system. In this system research projects are sometimes offered as optional alternatives to the "professional development" courses (design, unit operations, laboratory) [11-13]. There are two exceptions to this rule: the Senior Thesis required by some universities, and the Thesis in the case of a combined B.S.-M.S. program (or any other type of five-year curriculum) [14, 15]. Despite some similarities, the European Diploma Thesis takes considerably more time and occupies quite a different place in the curriculum as compared to the American Senior Thesis (Table 1). On the other hand, the various five-year programs either represent a minor side of the American system, or show some convergence to the European approach.

IMPACT ON THE ACADEMIC ENVIRONMENT

Table 2 summarizes the direct beneficial effects of required undergraduate research on the life of the academic community. It is obvious that these advantages are exactly the same in both educational systems. But there are some quantitative differences: according to the European system the whole graduating class is affected instead of a fraction and, at the same time, the effects are usually stronger due to more favorable conditions (time, supervision, supplies, financial support—as described in Table 3).

Nevertheless, the examination of the indirect consequences shows that there are also qualitative differences between the two educational approaches. The required research system, by familiarizing the students with the idea and practice of scientific research, tends to increase the percentage of graduates who want to continue their studies: 30-40% of the NTU graduating class, compared to less than 20% of the average class in the United States [16]. This increased supply of chemical engineers with a higher degree will be more useful in meeting the increasing demand of industry for specialized staff. But, what is more important is the realization that a greater number of Ph.D.'s are attracted by the idea of an academic career and want to become members of the academic community. Thus there are fewer problems for faculty renewal, and the whole university life becomes healthier.

The logic of the American program does not necessarily lead to undergraduate research projects, since research in the mind of the student is associated with postgraduate studies.

TABLE 2
Major Beneficial Effects of Undergraduate Research on Students and Faculty

1. Application of abstract knowledge.
2. Review of material covered during previous semesters; detection of possible "gaps."
3. Some specialization in a specific field.
4. Increased contact between members of academic community; better understanding of particular educational problems.
5. First experience in scientific research; familiarization with research methodology and discipline.
6. Training in literature searching.
7. Possible publications; preliminary results for future work.
8. Experience in oral presentation and report writing.
9. Contribution to the maturation process of the young engineer.

On the contrary, a similar analysis of the American system would reveal the tough competition between industry and universities at all levels (B.S., M.S., Ph.D.) [17, 18], the weaknesses of the latter [19], and the peculiar role of foreign postgraduate students (more than 40% of the total) in this system [20, 21]. It seems that, indeed, there is some relation between the lack of a certain research experience in the curriculum and some major problems of the American academic life. But does "more research" automatically mean fewer problems, and better education?

SOCIAL, CULTURAL AND ACADEMIC FACTORS

Both the American and the European educational systems are fruits of specific academic, cultural and social conditions. Since the conditions in the two cases are basically different, it is not enough just to point out the effects of undergraduate research and, then, compare them. Instead, we must try to understand the different role played by research in the two curricula.

A primary difference between the undergraduate classes in the two major systems lies in their homogeneity. To enroll, the European student normally has to pass a series of nation-wide examinations in Mathematics, Physics and Chemistry. It must be noted that the chemical engineering freshmen at NTU always belong to the top 10% of the candidates. As a result, the class is more homogeneous and responds more uniformly to all educational stimuli, compared with the average American class.

TABLE 3
Organizational and Financial Conditions of Undergraduate Research at NTU

MAJOR PROBLEMS	GIVEN ANSWER
Time	Open Labs, seven days a week, day and night.
Supervision	1:1 to 8:1 students: supervisor; approx. 50 hrs/student/supervisor/ semester; occupation recognized as a teaching tool by the University.
Supplies	Provided by the Department.
Financial Support	Department covers report writing expenses.
Total Cost	Estimated $250-450/student/ semester.
Space	Same used for laboratory experiments (no other regular activities scheduled during that time); approx. 50 ft^2/student.

A second difference is related to the stronger mathematical background of the students in Europe. This can be explained on the basis of the regular high-school education plus the highly selective procedure that precedes enrollment in European countries. To give an example based on the author's personal experience, the average student at NTU cannot accept any new mathematical formula without a proof, while in the American class the same formula is regarded as a tool for further application; therefore, a strict proof is not always necessary.

However, all kinds of research are characterized by a disciplined approach which proceeds through strict reasoning. For that reason, the preparation of the Diploma Thesis is, more or less, a logical consequence of the European system, a real crown of the whole undergraduate program. On the contrary, the logic of the American program does not necessarily lead to undergraduate research projects, since research in the mind of the student is associated with postgraduate studies.

At the same time, the social attitude towards academic activities is different in the two systems. Traditionally, the European university professor has been a figure of high social status. Scientific titles like Dozent and Doctor have both a high academic and a social value in Europe. Consequently, teaching (and especially research) are treated with a deep respect, even outside the academic community. Of course, these features force the European education to a more conservative and less productive attitude, as has been proved by the evolution of the European system.

CONCLUDING REMARKS

Research is a necessary ingredient of the European program. It comes as a logical consequence of this system and it permits its reproduction; this is why it is a prerequisite for graduation. On the contrary, the perpetuation of the American system is based on a "free market" model, where each university degree has a certain marketability [22]. This idea has led, logically enough, to the separation of research from undergraduate education. The short-term effects of this "divorce" contributed to a remarkable increase of efficiency. But, gradually, the long-term effects move the system in the opposite direction. In this context, any "injection" of more research into the curriculum will give only a temporary relief. What is possibly needed is a careful readjustment of the whole program. Already in the process of rediscovering the virtues of undergraduate research, American chemical engineering educators could find particularly rewarding a study of the European experience. □

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CONCLUDING REMARKS:

N. A. Peppas

In general, undergraduate research is viewed as an important part of the chemical engineering curriculum. Students develop a sense of independence and exercise their creativity. For the professors this interaction could be the solution to important preliminary research questions, which may eventually lead to submission of a research proposal, or solution of a "smaller" industrial research problem. In many cases the research is of such caliber as to lead to publication in refereed Journals.

However, there are major problems to be overcome. In schools where undergraduate research is not a requirement, faculty time spent on the projects is not usually recognized. Funding, especially for purely experimental research, is rather difficult to obtain and despite the existence of many educational grants (e.g. NSF etc.), most of the research of this sort is carried out through departmental funds, industrial unrestricted-use funds, or as part of a funded research project. One major problem without solution is laboratory space.

Since the completion of these contributions, several relevant articles appeared in the literature. Further information on the shortage of ChE graduate students was provided by Prof. A. B. Metzner (*Chem. Engin. Progr.*, 76 (10), 20, 1980). The recently published *History of Chemical Engineering* (W. F. Furter, Ed., Advances in Chemistry Series, Vol. 190, ACS, Washington, D.C. 1980) is an excellent reference for the work of Prof. Koukios in this issue. □

ChE book reviews

PRINCIPLES OF INDUSTRIAL CHEMISTRY
By Chris A. Clausen III and Guy Mattson
John Wiley & Sons, New York, 1978. 412 pages.

Reviewed by Max S. Peters
University of Colorado

The stated purpose of this book is to help chemistry students make the transition from the academic to the industrial world. In reality, the book is an elementary treatment of chemical engineering written in a way to make it understandable and useful for chemistry majors. Most of the fourteen chapters give a basic introduction to the chemical engineering of the topic indicated. Thus, the second, third, and fourth chapters on basic considerations, material accounting, and energy accounting are simply a brief over-view of the ideas of material and energy balances as presented in any of the standard chemical engineering books used for the sophomore chemical engineering course. Chapters 5, 6, 7, and 8 on fluid flow, heat transfer, kinetics, and separation processes are elementary presentations of what is given in all chemical engineering principles courses. The remaining chapters on instrumentation, developing the process, chemical patents, economics, and research are interesting reading, but they are highly qualitative and are greatly generalized. The final chapter is a good coverage of the overall aspects of the development of a process for the production of urea.

The book would be of essentially no interest