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Invited Review

Double Major Programs in Materials Science and Civil, Electrical and Mechanical Engineering at the University of California, Berkeley

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I. INTRODUCTION

Double major programs at the University of California, Berkeley, are arranged so that they include all of the core courses in two engineering curricula. They are jointly supervised by two advisors, one from each of the participating departments. The advisors work closely with each other to provide individual students with the best possible combinations of courses and schedules. Double major programs of study are intensive, but they can be completed in four years.

Curricula combining Civil Engineering/Materials Science and Engineering, Electrical Engineering and Computer Sciences/Materials Science and Engineering, and Mechanical Engineering/Materials Science and Engineering were activated three years ago. All of these programs have been exceptionally well received by engineering students and a fourth one has been recently added — Nuclear Engineering/Materials Science and Engineering. Faculty members in the major engineering departments have also been pleased with the success of the double major programs. The effect on enrollment in the Department of Materials Science and Engineering has been especially gratifying, indicating the fulfillment of a need for the improved understanding of engineering materials by students in other engineering departments, particularly those concerned with programs involving engineering design. In each of the ten years preceding the introduction of the double major programs the total number of undergraduate students majoring in materials science (metallurgy and ceramics) was approximately ten. During the first year of double major offerings, before any significant amount of publicity was given to the new programs, the enrollment doubled in the Department of Materials Science and Engineering. In the second year, the enrollment increased to forty, and during 1974-75 the enrollment increased to over seventy, with 60 being double majors. It seems highly likely that in another two years the enrollment will exceed 100 students.

During the second year of operation, a concerted effort was made to bring the double major programs to the attention of a larger number of engineering students. By this time descriptions of the programs had appeared in the Engineering Bulletin, the publication which describes in detail the engineering curricula offered at Berkeley. Special announcement posters were placed on bulletin boards in the engineering building complex, and mention was made of the double major programs in some of the engineering classes. After the second year, students already enrolled in the programs became effective recruiters, bringing additional students into the programs.

Employers and students alike have become increasingly aware of the advantages associated with knowing more about the nature of the materials used in engineering devices, equipment and structures. The double major programs were organized to provide students (most of

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whom expect to become design or manufacturing engineers) with the background knowledge of materials science related to their areas of interest.

Double major programs were conceived by Dean George Maslach (now a Provost of the Berkeley campus) as a means for providing increased breadth in engineering curricula. He worked diligently for several years to convince department chairmen and faculty committees of the merits of broadening undergraduate programs. At that time the number of technical electives available for breadth studies were very limited and often restricted to additional courses within the student's major department. For example, in 1960-61, in civil engineering six of the total of eleven semester units had to be selected from specified courses, most of which were within the Department of Civil Engineering. In addition, the suggestion was made, "however, students may elect to take the whole of eleven units of technical electives in their specialty". Electrical engineering students were also advised or required to take nearly all of their restricted electives within the department. The mechanical engineering curriculum had more freedom of choice than the other two, with twelve semester units being available for technical electives for additional specialization or breadth.

As a result of Maslach's efforts, much more open programs have evolved. In contrast with the earlier restricted choice of technical elective courses, civil engineering now has eighteen quarter units (twelve semester units) of unrestricted technical electives. Electrical engineering (which has become Electrical Engineering and Computer Sciences) offers programs in electronics, systems, computer sciences and bio-electronics. The coupling between Electrical Engineering and Materials Science and Engineering has been in the field of electronics. This option now has 56 quarter units (37.5 semester units) available for technical electives. In a single major program students are often advised to take most of the 56 units within the Department of Electrical Engineering and Computer Sciences, with the remainder of the units being in the fields of physics, mathematics or computer sciences. However, for students interested in combining the knowledge of materials science with electronics, the double major program makes it possible for them to take twenty of the elective quarter units in the Department of Materials Science and Engineering. The double major program with mechanical engineering was easier to formulate than the other two because of the relatively open technical elective selection offered in this Department before the inception of the combined programs. Faculty of the Department of Materials Science and Engineering worked closely with Dean Maslach to formulate and initiate the double major programs.

In 1973-74, an additional double major program was organized between the Department of Nuclear Engineering and Materials Science and Engineering. Also, the Department of Nuclear Engineering, following the lead of the Department of Materials Science and Engineering, introduced another series of double major programs with the other major departments. These programs have only been in operation for two years; they too have proven to be popular with students. They have provided additional breadth of study in an area that could benefit by a strong emphasis in training in two important engineering areas.

The double major programs at Berkeley were not externally publicized during the first three years of operation; nevertheless, rumors of the programs' success spread to other institutions. In view of the success that these new offereings enjoyed, it seems worthwhile at this time to publish a status report. As part of the background material, opinions about the programs were solicited from experienced educators at other institutions. A brief description of the program and a questionnaire were sent to the Chairmen of approximately 100 Materials Science and Engineering (and Metallurgy) Departments in the United States and Europe. Sixty-eight replies were received, a large majority of which expressed the thought that double major programs were worthwhile additions to engineering college offerings. The results of the questionnaire will be discussed in a later section.

II. DETAILS OF DOUBLE MAJOR PROGRAMS

The basic lower division program in engineering at Berkeley emphasizes the fundamentals in the fields of the physical sciences, mathematics and engineering but also includes studies in the social sciences/humanities area. The first

two years prepare students for entrance into specific majors at the Junior year level, although a major field may be chosen earlier if desired. The lower division program consists of 24 units of mathematics, which include calculus, linear algebra, calculus of vector functions and differential equations and related topics. Also included are nineteen units of basic physics and eight units of general chemistry. Other basic courses include an introduction to computer programming, engineering graphics, engineering mechanics, introduction to electronics and properties of materials. In the first two-year program, fifteen units are required for each of the six quarters.

To qualify for the B.S. degree in engineering, a student must complete 180 quarter units, half in the lower division and half in the last two years. All students, regardless of the major field, receive the same degree, *i.e.*, the B.S. in Engineering. The distinction between fields is indicated by the major field of specialization, such as Civil, Electrical, Mechanical, Nuclear and Materials Science. The introduction of the Double Major programs makes it possible for a student to qualify for a B.S. degree with two major fields, such as those previously indicated. Prior to the introduction of the new curricula, college regulations specified that a student must complete thirty upper division course units in a department in order to qualify for a major. This regulation had to be amended to read "30 units in a subject matter area" in order to make it possible for students entering double major programs to complete in four years the 180 units required for graduation. Students fulfill the 30 unit requirement by taking 20 units of Materials Science in the Department of Materials Science and Engineering and 10 units of Materials Engineering in the main engineering department. The twenty units of basic core courses in Materials Science provided an understanding of the nature and behavior of solid materials, and the ten units of Materials Engineering, which is taught by the faculties of the participating departments, provide the background information on properties of materials used in specific areas of engineering. For example, in Civil Engineering, courses on the properties and nature of cements and concrete, wood, structural steels and soils provided materials engineering knowledge appropriate for students in that field. In Electrical Engineering, courses in quantum mechanics, atomic physics, solid-state physics and properties of semi-conducting materials provided the required additional ten units of materials courses. In Mechanical Engineering, courses in mechanical behavior, processing, plasticity, metal forming, welding and casting and continuum mechanics provided the required additional ten units.

Five basic courses in materials science are required of all double major students. These include four units of crystal chemistry and diffraction (including laboratory), four units of phase equilibria and transformations (including laboratory), four units of thermodynamics and two or more of the following courses (depending upon the student's field of interest): physical metallurgy, chemical processing of materials, electric and magnetic materials, dislocation theory and mechanical properties, glass and crystalline ceramic materials, ceramic and metal powder processing, particulate materials or materials process engineering.

III. RESULTS OF SURVEY

As mentioned above, questionnaires were sent to 100 chairmen of departments in the United States, Great Britain and Europe where programs of study in materials science or metallurgy are offered. Sixty-eight replies were received. The following questions were asked:

1. (a) Do you think that Double Major Curricula are a worthwhile addition to engineering college offerings? (b) If so, what are the strengths as you see them? If not, what are the weaknesses as you see them?
2. Would you be interested in exploring the possibility of initiating Double Major Programs at your institution?
3. Are your relations with the large engineering departments favorable enough for operating cooperative, interdepartmental programs successfully?
4. Are there enough technical elective units available in the major engineering curricula to make possible the initiation of Double Major Programs? If not, do you think it is possible to liberalize programs so that the number of technical elective units would be adequate?
5. Is there any academic legislation that would prohibit initiating such programs? If so, are there procedures available for changing the restrictive rules?

The answers to question 1(a), "Do you think

that Double Major Curricula are a worthwhile addition to engineering college offerings?", were categorized as yes, no, uncertain and not relevant. A total of 39 replies were received from institutions in the United States; 35 (90%) answered yes, three indicated uncertainty and one indicated that the program was not relevant at his institution. Eleven of the seventeen replies from Great Britain were yes, one was no, and five indicated that the program was not relevant at their institution. Three replies were obtained from German institutions, two of these answered yes, one, not relevant. From each of the countries France, Belgium, Yugoslavia and Israel, one reply was received and in each case the answer was yes. From Austria, one reply was also received — the answer was no. The remaining four replies were from Canada, with one yes, one no and two uncertain. In summary, fifty-three (78%) of the replies were favorable, three were negative, five were uncertain, and seven indicated that the educational program proposed was not relevant to their type of educational system.

Part (b) of the question 1, requesting opinions about the strengths and weaknesses of such programs, elicited the following responses from chairmen of departments in the United States.

"Increased interdepartmental interaction, increased enrollment, program flexibility."

"Especially worthwhile for improving the viability and involvement of materials technology in college programs. Provides an opportunity for training materials people with a design perspective, thereby satisfying a real need. Provides a broader base for the students to develop further through professional experience or additional study."

"They permit a flexible approach to curriculum planning, while maintaining traditional standards of achievement."

"The combination of design and expertise in materials should be attractive to many students. Too often the design engineer does not have a good enough knowledge of materials."

"Materials engineering is a critical area for many engineers today and will increase in importance as material availability becomes more restricted in the near future."

"I feel that a considerable segment of the practicing (*e.g.*, designers specifying materials) M.E.'s and, to a somewhat lesser degree, the ChE's, CE's and EE's need a relative strong base in Materials; if not a double major, then a strong minor. From your experience at Berkeley it would appear that the double major may be more effective of overcoming materials engineering's perennial recruiting difficulties. Perhaps there is a considerable pool of students who are attracted to Mat. E., but don't want to put all of their eggs in that basket."

"It enlarges the scope of education. It makes the student more marketable."

"Since most engineering jobs involve the knowledge of materials properties and behavior, this double major gives the student an opportunity to get an excellent background in materials while still remaining a mechanical, civil or electrical engineer. I also believe that this double major emphasizes the importance of materials in all engineering disciplines and will undoubtedly attract more students to the studies of materials."

"Broadening the base will permit the students a wider choice of areas of specialization in graduate schools or in industry. Flexibility in designing the curricula for changing needs of the student and industry."

"Rather than being a 'diluted' civil, mechanical, etc., engineer, the graduate is a 'focused' engineer. He can focus on materials and their relationship to his field. This is often done in practice by imitation materials specialists with unsatisfactory results."

"Relative broadness and emphasis on principles rather than applications."

"Many jobs now call for just this combination. In the future, I think more opportunities will be of this type."

"The obvious benefit of your double major program is that it provides the opportunity for students in varietal engineering disciplines to get a sound introduction to materials science, training of vital importance to all areas of engineering, that normally they would not receive.

Another benefit is that the program must attract many students who eventually become materials scientists and engineers. Without the double major program these same students might never become acquainted with the opportunities our field has to offer."

"There are many strengths; principle one, it provides the ability for design oriented students and others to develop expertise in the properties and treatments of materials which they will later utilize in design. The double degree offers an incentive in developing this expertise. The program also formally encourages a broadening of curricula across disciplines, breaking out to some degree of the normal departmental parochialisms. Lastly, it proves an additional source of graduate students in materials."

"The strength, in my judgment, is that all fields of engineering need to be concerned with materials since in most processing and operations materials turn out to be the limiting factor in what can be done."

"Students have broadened their base for their future engineering career. It also increases their options on positions. Some students might do better focusing on a masters program at the beginning of third year."

The following quotations were taken from the seventeen replies received from institutions in Great Britain and Europe that favored the double major curricula:

Comments from Great Britain

"Exposure to different ideas and techniques produces more flexible graduates, prevents graduates from tackling problems from too narrow a viewpoint. Particularly useful for engineers, as many engineers know too little about materials."

"The design of a program of this kind encourages patterns which are somewhat more coherent than a single major program (even though this may seem a paradox). There is less of the à la carte and more of the table d'hôte. Also, as you say, it enchances career options and that seems to loom even larger for schoolboys."

"They will be valuable in attracting students with specific interests and final objectives. They will also appeal to a different set of applicants from those normally attracted to metallurgy."

"Wider employment opportunities. Better educational experience for the student."

"A double major is likely to provide a more realistic appraisal of the uses of materials."

"It seems to me that a thorough knowledge of materials is an essential part of many engineering activities. Our present programs do not provide the adequate materials training for engineers."

"Provides a wider field of competence and employment for the graduate."

"The engineer is probably better trained, although slightly less specialized, because of the wider issues involved."

"I consider that your wide ranging double major combinations are a considerable educational achievement, particularly as they represent such a high level of interdepartmental cooperation. My thoughts on the utility of the double major graduate echo your own. While there is a continuing need for 'Materials' graduates (both in the US as judged from my seven years with Honeywell, and in the UK as noted from my contacts with industry), there is a much greater demand for the Production and Design Engineers *with* sophisticated materials knowledge, *i.e.*, what is an 'equivalent' alloy, what is the effect of heat treatment/processing on mechanical properties, etc. Hence the employment situation justifies both 'Single' and 'Double' major programs. Additionally, the double program gives wider scope and relevance to the undergraduate student."

"The undoubted need for Design Engineers in all fields to know about materials so that they can make wise decisions about choices."

Comment from Germany

"There is a lot of industrial technology which can better be done by double major men."

Comment from France

"Provides better career opportunities to the student."

Comment from Belgium

"They help avoid a too much biased education, they produce a larger number of materials-minded engineers."

Comment from Israel

"A subject like Materials Engineering is very important when taken together with the traditional engineering fields."

Comment from Yugoslavia

"Students obtain education more useful for their work as design engineers since traditional courses often give education which include

courses not needed by some design engineers."

Comments from the three who replied No to the first question:

"The program might suit the odd student proceeding to graduate work. I feel that attempting a double major in four years dilutes both major fields of interest. You have more breadth, but depth suffers. We find that four years is barely sufficient time to turn out a student with a single major."

"They produce considerable dangers that the quality of focus provided by two separate Honors programs in two separate departments will not allow the student to develop a belief that his studies are relevant to the sort of occupational role that he will fulfill on completion of his studies."

"We tried something similar. We succeeded in producing either physical metallurgists with a smattering of mechanical engineering or mechanical engineers with a smattering of materials science. Neither should warrant a 'double major degree' ! It would take a quite exceptional student to earn one. Even so, our graduates were well received by industry. Obviously, there is some merit to efforts such as yours, and ours."

Replies from thirty-three (85%) institutions in the United States indicated that there was an interest in exploring the possibility of initiating double major programs at their institutions (question 2). In ten (34%) of the replies from other countries, there was a definite interest expressed. The comments received are listed below:

"A preliminary proposal is underway."

"We have a system whereby the double majors can be easily accommodated."

"We are currently looking into the possibility."

"Yes, with respect to EE, mechanical and aero."

"We have such programs, but they require an additional six courses (on top of a required 48 courses for a B.S.)."

"Our college will explore the possibility of initiating double major programs at all levels."

"Yes, although the time is probably not quite right."

"Already have similar program: Materials Option in Mechanical Engineering."

"We already have initiated Double Major Programs at Rice University. Many engineering graduates, notably in mechanical chemical engineering, return after several years of industrial employment with the intention of learning more about materials. They feel that a stronger background in materials would have helped them immeasurably in their work. This hindsight knowledge could have been corrected earlier, if the students would have opted for a double major in materials and another engineering discipline. It is important, however, that engineering students be made aware earlier of the need for a strong materials background in most industrial positions. We are trying to obtain this by offering a freshman engineering course dealing with some of the materials aspects of engineering. We would be grateful to hear about other ways in which this materials consciousness could be fostered among students in their freshmen and sophomore years."

"I would be interested in pursuing something like this, but because of the conditions here it would probably have to be modified rather considerably. Possibly a strongly emphasized minor in one or more programs."

"We are, in effect, doing that now, utilizing the fact that a number of engineering departments have designated core curricula which are small enough that core curricula in two departments, plus some electives, can be fitted into many schedules of better students."

"Presently have double major programs requiring thirty semester hours additional work about the first B.S."

In regard to question No. 3, which was concerned with the interdepartmental relations, 38 (56%) of those who replied indicated that there would be no difficulty due to interdepartmental relations. Ten from the United States commented as follows about possible uncertainty or problems:

"This remains to be seen."

"Entrenched undergraduate departments do not appear to be enthusiastic supporters and may actually be opposed to the idea."

"Yes, but in some cases resistance to this idea might arise if students are attracted from other majors in significant numbers."

"Not really, but persistent students can develop programs that are acceptable to both departments for the dual degree.

"My relations are, but the campus situation is not."

"The inherent jealousies of student acquisition and retention need to be questioned and resolved before a satisfactory climate can be expected for a Double Major Curriculum."

"Not sure."

"Probably yes, but the large size of departments has favored our approach to doing an interdepartmental program under the auspices of a general degree within the college of engineering — with combinations of majors in departments."

"This would be a problem to some extent."

"The most difficult problem is that faculties from other departments agree in principle about the need to incorporate materials science, but do not wish to give this as an option to the students, but as an added burden."

Comments from institutions in Great Britain and Europe

"At present, too few engineers appreciate the contributions that materials studies can make. So that whilst relationships are good, overtures are not taken seriously."

"Not entirely. Engineering courses are to some extent influenced by the requirements of professional engineering bodies and cooperation with the departments is hampered to some extent by this."

"Our relations with the design groups in mechanical engineering are very good and we could operate interdepartmental programs with them. However, the general views of the departments at the present time are not in favor of double major type programs."

"Considerable discussion would be required."

Question No. 4, which was concerned with the availability of technical electives in sufficient numbers to make a double major possible, received the following replies:

In the United States, seventeen institutions replied that there were enough electives available to accomplish this objective.

There were seventeen replies from institutions within the United States which indicated that there were not enough electives in the normal engineering program, except in a few cases where the possibility existed with the department of mechanical engineering. Only three of the departments indicated that it would probably be possible to liberalize programs so that the number of technical elective units would be adequate. Most of the others indicated that it would be difficult or impossible to do so.

Of the replies from Great Britain and Europe, fourteen of the 23 replies indicated that there were enough electives to permit the initiation of double major programs. Two of the others indicated that there were not enough electives and the remainder made either no reply or indicated that the elective system was not used at their institutions.

In regard to the replies to question No. 5, concerning academic legislation that might prohibit initiating double major programs, 29 (74%) institutions in the United States indicated that there would be no problem involved in this regard. Similar answers were obtained from thirteen (57%) of the replying institutions from Great Britain and Europe.

IV. CONCLUSIONS

The concept of double major programs was favorably received by most of the institutions in the United States and Europe. A large majority of the department chairmen replying to the questionnaire indicated that they would be interested in exploring the possibility of initiating double major programs at their institutions. Most of them also indicated that the relationships with other departments were favorable enough so that it might be possible to formulate such programs, and that there was no prohibitive legislation that would prevent their doing so.

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