engineering graduate school is considerably higher than the national average. Surprisingly, only about 25 percent of the students who went to graduate school chose a graduate research topic in biomedical engineering. The results obtained by the survey are very similar to the experiences encountered by this instructor over the past three years [2].

There is general agreement among the professors that the job market for BS chemical engineers in biomedical engineering is non-existent. For the PhD level the opinions are varied, ranging from poor to excellent. There is general agreement that the job market is small. Most professors feel that the demand for PhD chemical engineers in biomedical engineering exceeds the supply. In Canada, however, there is practically no demand at all, although predictions for the future are good.

In summary, it appears that biomedical research projects are useful in a chemical engineering department in order to provide interesting and stimulating research topics to undergraduates. Many of the undergraduates continue their studies at an advanced level, but not necessarily in the area of biomedical engineering. The productivity of the students appears to be excellent as judged from the number of publications. It should be pointed out to those undergraduates with a strong medical interest, that the job market on the BS level is poor. □

REFERENCES

1. Peppas, N. A. and R. Mallinson, "Teaching of Biomedical Engineering in Chemical Engineering Departments," 73rd Annual AIChE Meeting, Chicago, November, 1980.
2. Stroeve, P., "Chemical Engineering Undergraduates in Biomedical Engineering Research," Proc. 1980 Annual Conf. Am. Soc. Engr. Ed., 2, 287-289 (1980).

PRINCETON UNIVERSITY

SENIOR THESIS RESEARCH AT PRINCETON

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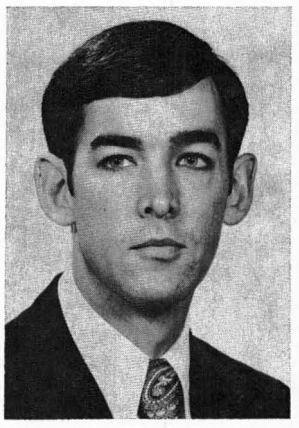
AN ACTIVITY WHICH IS as much a part of spring at Princeton as the blooming of the tulip trees at the Woodrow Wilson School fountain is the scheduling of our forty-to-fifty seniors to present the results of their senior thesis research to their thesis advisor and one other faculty member designated as the second reader. The Herculean task of finding free time slots amidst busy and conflicting schedules falls to Professor Dick Toner, the departmental coordinator for senior thesis work. At about the same time the juniors are making the rounds of the faculty discussing topics for next year. The students select topics after Dick Toner has arbitrated conflicts and sought, to some degree, to equitably match student interest and faculty availability.

The senior thesis at Princeton is not an option for a few good students, but is rather an integral part of the educational process for all our students. Between 1950 and 1956, senior independent research projects were offered as an alternative to a laboratory class associated with the senior-year chemical engineering design course. With class sizes then being in the teens, the senior thesis process was rather informal. In 1957 the senior thesis was made mandatory, and the design laboratory was discontinued. Our present policy requires that all seniors do thesis work; however, each year we grant exemptions to two or three students who plan to attend medical school or business school



Robert K. Prud'homme did his undergraduate work at Stanford University in Chemical Engineering, followed by graduate work at Harvard University in Environmental Engineering before he "saw the light," returned to Chemical Engineering, and obtained a Ph.D. at the University of Wisconsin—Madison. He joined the faculty of the Chemical Engineering Department at Princeton University in 1978. In what little spare time is available he avidly reads the fairy tales of C. S. Lewis, J. R. Tolkein, and George Mac Donald. He plays a passable game of squash, and drives a rather battered 1968 Volvo.

after graduation in order to allow them to take additional specialized coursework outside chemical engineering.

Having described briefly the mechanics and history of senior thesis research in our department, in the next sections I will first describe the strengths of this type of experience for the student, and then point out what seem to be the requirements for a successful senior thesis program.

SENIOR THESIS AS INSTRUCTION

The first and most important goal of senior thesis research is to provide a unique learning experience for the student by providing a context wherein students learn creative problem solving in the following ways:

Problem Definition. In my opinion, this is the strongest argument for a year-long independent research project. The common lament with laboratory courses or problem sets is that they must be well defined and tightly constrained to enable students to complete them before the next assignment. Those of us who have made up homework problems know that the step from an initial idea to a well formulated problem on a sheet of paper is most often more difficult than solving the problem once it is posed. The activity of problem formulation is lacking from most curricula because it is difficult to teach; this is just what independent research teaches. The student begins with an idea or concept and has to design a strategy, either experimental, analytical, or numerical, to test that idea. This process teaches problem formulation.

Introduction to Reference Material. Because the projects are research projects rather than textbook problems, students are forced to read basic sources such as journals and technical reports for information. Often this is a student's first exposure to these sources and the resulting appreciation for the value of current research in scholarly journals and reports is of great benefit whether they later go to industry or graduate school.

Student/Faculty Relationships. This is an intangible but real benefit. Through a one-on-one relationship with their thesis advisor students get to know a faculty member in depth. In weekly meetings the student sees how a faculty member "mumbles out loud to himself" about the problem

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at hand. Relationships built in this way are reflected in the high morale of students in the department. It also lets the faculty member get to know a student well enough to make informed recommendations to future employers or graduate schools.

Sense of Accomplishment. My students have all had a strong sense of accomplishment after the thesis work was finished (although the process often led through Pilgrim's "slough of despond"). They have mastered a problem area in depth, synthesized training from several undergraduate courses, and have engaged in creative problem solving.

SENIOR THESIS AS RESEARCH

In addition to the pedagogical aspects, the senior thesis research also fits into the research objectives of our department. The thesis provides several benefits to the faculty:

Investigation of New Areas. All of us have had wild ideas from time to time that generally spring upon us late at night like Kekulé's dream. Sometimes these are great ideas, sometimes they are just terrible. But we would like to try them out. They are too preliminary to warrant submitting a proposal to a funding agency, and the chance of success may be too uncertain to commit a graduate student. At Princeton however, if a senior agrees that your wild idea has merit, then you can both try it out. This has been an effective method for exploring new research areas and obtaining preliminary results upon which to base proposals to a funding agency.

Assistance on Funded Projects. Often, on funded projects where a graduate student is doing doctoral work, an undergraduate can provide valuable assistance by doing research on a subproblem. For example, one of my graduate students is studying gas bubble nucleation in polymer solutions. In support of this research a senior has been determining the surface tension of polymer solutions at elevated temperatures which we needed in the theoretical analysis of the nucleation phenomena. The obvious should

be mentioned—this help with funded projects comes without salary and overhead costs.

Industrial Interaction. In recent years several thesis projects in the department have been sponsored by industry: Du Pont, Hercules, Smith-Kline, and the Textile Research Institute, to name a few. This mode of interaction benefits industry in their communication with students and the department, and the students are uniformly enthusiastic about working on problems of "industrial significance."

PARAMETERS FOR A SUCCESSFUL PROGRAM

After discussions with colleagues at other institutions it became clear that the pattern of thesis research at Princeton may not be transferrable to other departments. There are certain ingredients that seem necessary for a successful program:

Faculty Workload. It is obvious that advising senior thesis research takes time and energy. In our department each faculty member advises between two and four seniors. If our class sizes grew such that the senior/faculty ratio was larger than it is, we would be hard pressed to continue the program as it is now constituted. Also, advising seniors is implicitly considered as a part of our teaching load so the number of courses we teach each year is kept reasonably low.

Ongoing Research Activity in the Department. Our department has an active graduate research program and this provides three necessary ingredients; ideas, support, and faculty involvement. Students are not interested in working on old ideas or repeating someone elses experiments. With an active research program there are always sufficient new ideas available to challenge the students. Also, our funded research provides the base of equipment and materials needed to pursue most projects. Lastly, faculty interest in a student's project is of paramount importance to a successful experience for the student and faculty member. If the student's project is in the mainstream of a faculty member's research interests the faculty member is more likely to supply adequate direction to the student and is more likely to keep abreast of the student's progress.

A University-Wide Thesis Requirement. Most chemical engineering curricula are regarded as being among the toughest in the university, as is ours, and an additional requirement of a rigorous senior thesis project might be perceived as an intolerable burden. At Princeton almost all departments require senior thesis and therefore our senior thesis requirement is not perceived as being at all unusual. This might not be the case at another university.

Student Quality. We are benefactors of Princeton's high admissions standards in that our students are bright and, by-in-large, motivated. Just the thought of dragging an unmotivated, unwilling, and ill-prepared student through a year of senior thesis research sends chills up my spine.

CONCLUSION

Our experience with senior thesis research has been positive both from the students' perspective and from the faculty's. It will remain an integral and distinctive part of being a chemical engineer from Princeton. In preparation for this article we sent a survey to our graduates. It is appropriate to close with excerpts from comments of the four hundred respondents on their retrospective looks at senior thesis research at Princeton.

> **1979:** The switch from the regimen imposed by a class schedule to the freedom allowed by independent work was an invaluable experience for me. Despite the fact that I switched fields upon graduation . . . I think the discipline I adopted in doing my senior thesis has, is, and always will serve to give me a head start.
>
> **1978:** The best "course" I took at Princeton. The experience of having written a lengthy paper provides valuable experience in an often neglected skill.
>
> **1977:** My senior thesis added enormously to my undergraduate education. One of the most valuable lessons . . . was that I had to define my own goals within the constraints of time and resources. I have found this to be extremely important in industrial research.
>
> **1975:** The senior thesis at Princeton is an invaluable tool for teaching one how to approach a problem, how to define it, and what is the measuring stick that will let you know when you have answered the questions you set out to solve. It is the closest thing to how we do work in industry that I experienced at Princeton.
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> **1974:** I did my senior thesis under Professor . . . . and it was through his stimulating guidance that I accomplished what I regard as my most rewarding and enjoyable academic experience at Princeton.
>
> **1968:** It damn near killed me, but it was the first really large project I had ever undertaken and finished by myself, and the experience was absolutely invaluable.
>
> **1964:** My undergraduate thesis experience provided an excellent foundation for my graduate thesis work fifteen years later. □