SOME THOUGHTS ON GRADUATE EDUCATION

A Graduate Student's Perspective

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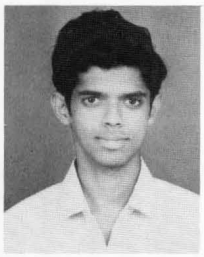
Chemical engineering may well be the most diverse of the engineering disciplines, and it is getting broader every year, with practitioners working in such far-removed areas as molecular genetics, microelectronics, and artificial intelligence. In fact diversity and adaptability may be the main advantages we have over other engineers. In the future, chemical engineers will have to be creative thinkers, using their knowledge to expand the frontiers of science, and we must give considerable thought right now to how we can prepare students to face that challenge. In response to this future need, quite a few changes have already been incorporated in the curriculum, but additional improvements will also be necessary if we are to keep pace with future developments and demands.

A natural consequence of progress is the increase in the standard at each level of education. For example, while I was not introduced to computers until the twelfth grade, today's eighth-grade students are already using computers. At the college level, it seems to me that converting chemical engineering into a multidisciplinary field has been reasonably well accomplished in the undergraduate curriculum, and that the curriculum has become more flexible. In order to prepare students for the next step (either graduate school or industry) a number of changes have occurred—undergraduate research being the most significant, in my opinion, since it gives the student a flavor of graduate school and research.

The logical sequence now is for graduate education to follow suit and to introduce students to some of the characteristics of faculty/industrial research careers. I do not claim that this has not already been done, but I do wish to explore opportunities for further improvements. I realize that there are professors who are better qualified and more experienced to address this issue than I am, but I would like to offer my ideas—from a student's point of view.



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By coming to graduate school, a student has already made a strong commitment to developing a deep understanding of some particular subject. The student has to have been motivated as an undergraduate; he or she is not there merely to get a degree. After completing the PhD, that student intends to be a leader in teaching, research, and/or development.

In order to prepare a student to face the diverse world of chemical engineering, some improvements in the curriculum are necessary. I will focus on three important areas—they are related to each other in the sense that success in one depends on success in the other:

- **Teaching and Course Work**
- **Research**
- **Communication and Motivation Skills**

TEACHING AND COURSE WORK

When I was an undergraduate, I participated in a debate on *"education is what you remember, after you forget what you learned."* It sounded odd at first, but I understood and supported it wholeheartedly later. University education teaches us many details (which most students forget as time goes by), but it is the basics (which are taught as a small fraction of the total duration) that must be retained. That we do not remember the details may not be a problem at all. In fact, the purpose of education is exactly what my debate topic was—to teach the "collective wis-

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dom." However, many students do not realize this and lose their motivation, especially at the graduate level, when they take what they think are irrelevant classes. While it is clear that details are necessary in certain situations, it is important to recognize that the *collective wisdom* is what helps us in the long run.

If the above statements are valid for undergraduate education, they are even more pertinent at the graduate level. It is imperative that the graduate curriculum emphasize new and abstract ideas in diverse areas. I will expand on a couple of suggestions in the following sections.

Encourage Creativity in the Graduate Classroom

There are two phases to any scientific idea: giving birth to a creative idea, and having the analytical ability to carry that idea to conclusion. Our education helps us to excel in the latter aspect, but not in the former. Some people even contend that creativity cannot be taught. While I cannot make a ruling on that, I do feel that it *can* be encouraged. In an article on graduate education, J. L. Duda[1] said, "...our educational system stifles creativity." We often see graduate classes where the student is asked to solve sophisticated versions of problems such as "given x and y, solve for z"—essentially similar to undergraduate classes. Such problems are illustrative in the short run, but do not help a lot in the long run.

Many students agree that the best thing (sometimes the only thing!) we remember from our undergraduate classes is the design project. However, most of us do not remember the details of Wei-Prater analysis. Why? Because the design project was open-ended and made us think about the practical aspects of what we learned, thus motivating us to understand and engrave it in our memory.

We should have at least a couple of classes in the graduate curriculum that are devoted to discussion of creative, open-ended problems. R. M. Felder[2] has had great success in such attempts in a graduate class. For example, he posed the problem, "You are faced with the task of measuring the volumetric flow rate of a liquid in a large pipeline. Come up with as many different ways to do the job as possible." There were some constraints[3] which I shall not list here, but he received two hundred different responses, illustrating that a seemingly straightforward question posed in an open way elucidates creative answers. It is not important that some of the responses were not commercially viable; what *is* important is that students were able to think creatively and to apply their acquired knowledge to the problem. Since graduate students have already had the basic courses, the problems need not be confined to one subject, but can be open and general. They may include case studies, previously solved problems, and unsolved problems.

The advantage of such a class is that it encourages students to think creatively, it stimulates learning from others' lines of thought (and improving on them), and it brings various aspects of chemical engineering together in a classroom setting. Some disadvantages could be that the students may be initially reluctant to participate because they are not used to such an approach (Professor Felder states, "...with a little practice the students become very enthusiastic"), it may take some time for faculty to create the right set problems for the course, and the evaluation method is subjective. (The fact that the graduate class is small helps in this respect, and at any rate, grades are not supposed to be that critical in graduate school.)

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Less Material, More Discussions

Classes should be more like James Bond movies. There should be something in them for everyone. Involving students in active discussions is a must, but unfortunately, many classes are simply monologues. There is usually some level of student interest in every class, and it is important that all the students get something out of the class. Even basic things such as explaining the day's topic in the beginning and summarizing major points in the end will ensure that students leave the class with *some* newly gained knowledge. It might reduce the amount of material covered in class, but it would be worth it because students would retain more of what was taught.

RESEARCH

These days one often hears of the importance of research with regard to on-the-job success. Upon graduation, the student is expected to come up with creative ideas, to write proposals, and to attract coworkers, among other things, and the first few ideas and proposals lay the foundation for his or her long-term survival. A badly written proposal in the

initial stages of a career can have drastic implications. Even though post-doctoral research provides time for working on these aspects of a career, it is better to begin at the graduate level where one has five years to learn and correct mistakes.

In most cases, a graduate student learns to take a single task to its conclusion while the research advisor dominates selection of the primary task itself. Efforts should be made to give the student practice in identifying new and important problems in multidisciplinary areas. This would provide students with the opportunity to test and use their creative skills. The following sections offer a few suggestions along this line.

Make Research Proposals Mandatory

Two-time Nobel Laureate at Caltech, Professor Linus Pauling, once said, "The best way to come up with great ideas is to come up with many ideas and later eliminate the bad ones." Every student should be required to write at least two original research proposals and to present them to the PhD committee. This requirement already exists in some schools. It challenges students to think about completely new ideas in related areas and opens them up to many new possibilities. To gauge the student's improvement, the proposals should be presented one year apart—once in the third year and once in the fourth, for example.

The disadvantage, if any, of making proposals compulsory may be that it takes away from the student's available time during his 'prime' and might impede his research progress. However, it helps in the overall growth of the student, and that is, after all, the primary purpose of graduate education.

Involve Students in Proposal Writing

It is common knowledge that the competition for research dollars is getting stiffer every year. This makes life for a new professor even tougher than it normally is. Graduate school could be a good starting point for training. If students are exposed to proposal writing, presentation, and potential funding agencies during the latter part of their PhD work, the experience will serve them immensely later on in their careers. While the ACS guide on proposal writing is helpful, real-life experience and examples are certainly more useful. In fact, it may also help the faculty since the students can critique technical content and improve the presentation to "outsiders." I understand that many faculty already do this.

Hold Student Seminars on Common Topics

This does not refer to the usual group seminars which are held to discuss research progress. It refers to seminars that could serve as vehicles for identifying good research. The emphasis should be on how to critically analyze a paper and to learn from its contents. The papers should be chosen such that they are either pioneering or classical, very good or very bad. In this way the salient features of ground-breaking research, good research, or bad research can be easily illustrated. A very good or very bad paper is like Madonna—it makes a statement and the point is easy to see. A just-okay paper is more like a politician—it is tough to learn anything quantitative from what it says. In order to add weight to the seminar and make it even more effective, it could involve only a small number of students. It might be more valuable to the students if it is offered toward the end of the first year or at the beginning of the second year when they are about to embark on their research projects. The meetings should be informal and should be filled with constructive discussions.

COMMUNICATION AND MOTIVATIONAL SKILLS

Communication skills are important for everyone. However, special emphasis on communication and motivational skills should be a part of graduate school. While it is incorrect to generalize, it can be said that most graduate students are relatively reserved and introverted. In fact, that may be one of their strengths! But after graduating and becoming professors, they will have to deal on a day-to-day basis with students, faculty and industrial groups, and as leaders in industry, they will have to interact with coworkers and other research groups. A leader must be able to motivate coworkers in order to achieve the desired results. *The importance of communication and motivational skills for success in the real world cannot be overstated.* It is imperative to stress their importance in the graduate curriculum. The best method for achieving this may be hard to identify, but some possibilities would involve a class on communication as part of the curriculum (taught by a communications expert), periodic communication and motivational workshops (with case studies), and an elective class on "How to Teach."

CONCLUSIONS

The growing diversity of chemical engineering demands constant readjustment of the graduate curriculum. In order to produce creative leaders who can survive the changing environment, I have suggested some curriculum improvements as seen from a student's perspective. I feel the most important aspect to be considered is to encourage creative thinking in teaching and research. In teaching, the value of discussion-filled, creative classes is stressed, and

in order to increase effectiveness in illustrating a concept, use of open-ended problems is suggested. In research, the requirement of original research proposals as part of the degree requirements and faculty-student interaction in proposal writing are additional suggestions for consideration. Efforts should be made to improve student communication and motivational skills since they play a vital role in later careers, whether in teaching or in industry.

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ChE ***book review***

MODELING WITH DIFFERENTIAL EQUATIONS IN CHEMICAL ENGINEERING
by Stanley M. Walas

Butterworth-Heinemann, Stoneham, MA; $145, (1991)

Reviewed by
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Today there is a recognized need for teaching a course in mathematical methods to undergraduate chemical engineers, and several schools have begun offering such courses. But there are only a few textbooks available that are primarily addressed to chemical engineering students. This book by Walas is therefore a very timely addition to the literature. It is an excellent book.

The book consists of fifteen chapters and an appendix. Chapters 1 to 7 focus on mathematical methods of solutions of ordinary and partial differential equations. Integral equations are briefly treated in Chapter 6. Theoretical discussions, such as existence and uniqueness of solutions, have been skipped and instead, emphasis has been placed on solution techniques and detailed applications. All classical methods of solution are covered in detail. Numerical and approximate methods are emphasized early on throughout the presentation. The material is well presented, and a wealth of references for further reading are provided. These chapters give the student a good background in the different methods (analytical, numerical, and approximate) for solving ODEs and PDEs. Limitations of the techniques are clearly explained, and methods for overcoming the difficulties are presented.

After the mathematics of differential equations has been presented, there is a chapter devoted to the principles of the mathematical formulation of engineering processes. What follows next is the distinctive part of this book—the derivations and solutions of differential equations of some of the major disciplines of chemical engineering. The topics covered include thermodynamics, mass transfer, fluid flow, heat transfer, chemical reactions and reactor design, and process control. Attention is restricted primarily to the differential equations that occur in these processes. Many of the topics are reinforced by mathematical or numerical examples as well as problems for the reader, most of them with answers provided.

Throughout the book the author guides the reader toward more comprehensive sources of information, and the reference list is excellent and up to date. Little mathematics beyond calculus is expected of the reader. Computer usage by the examples and problems is restricted to readily available user-friendly PC diskettes. The treatment of most topics is fairly complete, and beginning students will not need to relearn the material as their sophistication advances.

Overall, this book will satisfy the demands of undergraduate and first-year graduate chemical engineering students who usually have difficulty in understanding the presentations in more general mathematics texts. The book may also be of value to those who have already mastered the typical chemical engineering curriculum, *e.g.*, the chemical engineering practitioner, and who are now involved in some aspect of computational or mathematical modeling of chemical engineering processes.

In summary, this is a highly recommendable textbook for senior and beginning graduate students, set apart by an easy style, a healthy amount of exercises, lots of references, and a wide coverage of topics. The author is to be commended for his excellent effort and contribution to the chemical engineering literature. ❐