ERRORS
A Rich Source of Problems and Examples[1]

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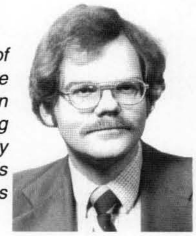
Engineering instructors are constantly on the lookout for new and better problems and examples to use in homework assignments, lectures, or examinations. Yet a rich source of these problems is generally overlooked: the numerous errors in textbooks or published articles, and even our own assignments and examination questions. Problems developed from errors simulate real-world situations in which engineers must catch and correct their own and other people's errors. They can also show students that real engineering problems are open-ended—not well-posed mathematical situations that can be solved simply by plugging new numbers into an old equation.



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WHY USE PEOPLE'S MISTAKES?

Engineers make mistakes. In fact, Petroski[1] presents a convincing case that errors are the driving force for engineering advances. Do engineering students typically confront this idea in school? Would they be more interested in their courses and would they more fully comprehend their future profession if they did?

Many of us try to prepare homework assignments and examinations that are straightforward: straightforward to write, straightforward to do, straightforward to grade. In fact, one criterion often espoused for a well-written test question is that the instructor can anticipate all possible student responses. The strong bias toward generating questions with as few conceivable responses as possible can result in a simple mistake (typographical or otherwise) rendering a question "unanswerable." If we uncover such an error (usually during the grading process), we apologize to the students (or try to cover up) and discount the grade for that question. After all, it was not the students' fault that the instructor posed an impossible question. We wouldn't want them to think that engineering problems are sometimes ill-posed, that they can be frustrating, or that they may not have an answer. Or would we?

Honest errors appearing in textbooks, articles, and instructor-generated assignments can serve as meaningful vehicles of instruction.

Textbooks and technical articles are full of errors. Some stem from the author's misconceptions and some are the result of inadequate proofreading. What happens to students faced with a homework assignment that (unknown to the course instructor) has a typographical error making the problem indeterminant? After much time and frustration the students finally give up, figuring that they will learn the solution in class. When the class meets, the instructor explains that the problem should have included an additional piece of information or a different equation, and if it had, it could be done in such-and-such a way. In a blaze of chalk dust, the solution to *a different problem* is presented, and the students dutifully write down this new question and answer. The same scenario may occur again and again, until the students are convinced that engineering problems can only be solved when they are presented in an error-free and well-posed form.

[1] This material was presented at the 1987 ASEE Annual Conference. Reference 2 is a more complete version of the paper.

Good engineering textbooks take years to write but most still contain numerous errors, many of which may be typographical (and presumably will be corrected in subsequent printings). . . . Most instructors find that the difficulty is not in finding textbook errors, but in deciding what to do about them.

One cannot really avoid using errors as a source of problems and examples. The choice is only how they will be used and to what end.

SOURCES OF ERRORS

Below are some examples of errors that I have used. The list is not meant to be exhaustive, it simply suggests where to look. More details are given elsewhere.[2]

Textbooks

Good engineering textbooks take years to write but most still contain numerous errors, many of which may be typographical (and presumably will be corrected in subsequent printings). To show what kind of problems occur, I will describe some errors in first-rate engineering texts that I have used. (In the interest of the authors, I will not cite the references.) There are, of course, many other examples of errors. Most instructors find that the difficulty is not in finding textbook errors, but in deciding what to do about them.

Missing Information In one homework problem that I have used, the conversion of a reactor is omitted from the problem at the back of a chapter. Without this specification, the problem is indeterminant—there are more unknowns than the number of independent linear equations that can be derived to solve for them. The instructor may assign this problem, skimming the problem statement and the solution in the Solutions Manual to be sure that the problem is of an appropriate difficulty. However, the Solutions Manual uses an 80% single-pass conversion in the solution, even though this information is not in the problem statement (and cannot be inferred from the information that is given). When they attempt this homework problem, students give up after reaching varying levels of frustration. The instructor often doesn't notice the printing error until a student asks a question about it during class as the instructor is going over the problem.

Corrected Printing Errors Very popular texts often go through numerous printings and it is not uncommon for some errors to be eliminated but others to be added. An interesting situation can arise when the instructor and the students have different printings of the same edition of the text. I have found three different versions of a problem in a text on numerical methods. In one version a printing error leads to a non-physical numerical answer; subsequently, an erroneous correction leads to yet a new problem. An incorrect assumption is made in the problem statement, but a footnote attempts to guide students to a correct solution. An additional misprint results in violation of the conservation of mass. Thus, the misfortune of the authors and the publisher of this fine textbook increases the richness of the problem several-fold, exposing the students to these concepts:

- **Printers make mistakes**
- **Equations may have to be reformulated if certain assumptions are not valid**
- **Footnotes are important**
- **Complex or imaginary numbers may be an indication of errors in problem formulation or computer programming**
- **Material balances should always be checked**

When I used the above problem in class, we ended up solving four different problems—the three flawed printed versions and the other "correct" version (which appears in none of the printings that I saw). The ensuing discussion of nonlinear equations, fluid mechanics, and problem-solving techniques lasted the entire class period and was one of the most worthwhile sessions of the semester.

Deliberate Errors Some textbook homework problems incorporate intentional errors. These problems range from reproductions of newspaper articles describing impossible processes to mis-specification of design variables. Students initially see such problems as "trick questions," but many problems incorporating deliberate errors provide ideal vehicles for teaching content and problem-solving skills.

For example, the "Ice Skating Problem," which appears in numerous thermodynamics texts, proposes that the pressure under the skate blade is great enough to lower the melting temperature of the ice to the ambient temperature. In this case, the thin layer of water that forms would lubricate the blade continuously, and this phenomenon would explain the very low friction that is experienced in ice skating. One expects students to recognize that they can use the Clapeyron equation to determine the pressure required to melt the ice and that they need to make engineering approximations and assumptions about ambient conditions, skater weight, and contact between the skate blade and the ice surface. Overall this is a very good problem, but the answer given in some thermodynamics texts (and solution manuals) is wrong. When the problem is looked at in detail, the melting-point depression is but one of *several* factors contributing to the low friction that makes ice skating such an exhilarating experience. The students learn that often many different factors contribute to phenomena and that the first one they think of may not be one of the more significant ones. Perhaps equally important, students gain confidence in their own abilities when they think of additional factors, especially if the textbook ignores them.

Difficult Written Passages Often, technical writing is dense—difficult both to write and to comprehend. One particularly demanding type of writing is the process description. Even in a first course in chemical engineering, students are confronted with process flowsheets consisting of over a dozen units, a score of streams, and a recycle or two. Our students must be able to develop a flowsheet from a verbal description of a process. This is a skill that the students will need in their profession, and it is a common and effective teaching technique.

Many texts and articles include process descriptions. The problem is that the descriptions are often difficult to read and to comprehend. The numerous interconnections in the process and the often unfamiliar process units often confuse students. They immediately realize that the description is difficult, and some even suggest that they could write a better, clearer process description.

Although a convoluted written passage may not properly be called an "error," it demonstrates that even well-respected authors have limitations. Students can learn a great deal about engineering (as well as about technical writing) by being asked to decipher dense prose.

Other Books

Engineering students read many books in their field other than their textbooks (or so we hope), and the errors in these references can also be a source of examples and problems. One example is a printing error in the solution procedure for cubic equations in the *Chemical Engineers' Handbook*.[3] I have not used this particular example in class yet since I feel the students may become *too* frustrated when trying to use the method presented. Instead, I alert the students to the error and ask them to correct the equations in their copy of the handbook. By bringing the error to their attention and describing the frustration they might have experienced had they tried to use the erroneous equations, I hope that they will learn the importance of verifying printed information rather than simply assuming that it is correct.

Articles

Trade Journals Many periodicals of this type are printed in a hurry and without peer review. As a result, it does not take long to find articles containing errors. I am especially fond of an article printed in *Consulting Engineer* entitled "Breakthrough! Electricity Without Fuel."[4] Reactions of engineers to this article are diverse. Some laugh when they read the title, realizing that it must be about a perpetual-motion machine, while others are puzzled by a simple sketch in the article showing how endless supplies of electricity can be obtained from the judicious and selective use of gravity.

As a first assignment in my graduate thermodynamics course, I give the students copies of this article and ask them to prepare short reports evaluating the process and proposing any improvements they would like to make. Many students with high grade-point averages suggest exotic process modifications backed up by "impressive" calculations. We spend an entire class period on this article alone, and the students learn much about the laws of thermodynamics and their consequences. They also become more confident in their own ability to think critically. (Note to the reader: If you get a copy of this article, please be sure to read the boxed items on the second page.)

Research Journals Anyone who has ever written an article, reviewed one, or read one, can see that research journals are a bounteous source of errors.

Other Newspapers and popular magazines often contain articles describing devices that could not possibly operate as described or data that are inconsistent. In the appropriate course, these can be fine sources of class problems.

Computer Programs

Most of the effort in writing computer programs is spent finding and correcting errors. Students quickly realize this during the first assignment. What they may not realize, however, is that most of their learning occurs during this debugging process. Some instructors have suggested that students should be required to debug each other's programs, but I have not tried this assignment, yet.

Our Own Assignments!

Instructors, mere mortals that we be, produce an abundance of flawed homework assignments and examination questions. While I do not suggest that we should be less diligent in trying to develop well-thought-out assignments, I do propose that some of our better problems may be those that have small, honest errors that make the problems more realistic and open-ended. There is, however, great danger in trying to introduce a trick error. Honest errors are more realistic, and they are certainly less upsetting to students.

HOW TO USE ERRORS

Some of the ways that errors can be used have been mentioned in the foregoing paragraphs. The following is a brief summary of these approaches along with some additional techniques. I have found some of these methods useful; others I have only thought about using. Although I cannot claim that any of them are guaranteed to work, I believe that they can be effective, and I encourage experimentation with them.

Assignments With the numerous printing and other errors in even the best textbooks, all of us have assigned (or soon will assign) a problem containing an error. Rather than an embarrassment, this is an *opportunity*. Instead of trying to minimize the error, the instructor can use it to explore the subject matter and help the students learn to ask appropriate questions. How far can one go in solving the stated problem? What minimum additional data are needed? What reasonable assumptions can be made about the missing parameters? Would it be expensive (or even feasible) to measure the missing values in a real situation? How might the solution to the problem differ for various assumptions about the missing data? How can errors be identified in the future? The list goes on and on.

Classroom Examples Using errors can be challenging (and even intimidating) for both instructors and students. A good way to introduce this approach is to use an example in a lecture. In this controlled situation, students will be less frustrated than they would when working on a problem at home. Some frustration is helpful, however. As in most circumstances, but especially when discussing errors, students must ask questions during the lecture or they will neither internalize concepts nor develop a strategy for dealing with errors. The instructor must be prepared for unexpected questions and be constantly aware of the students' need for structure and for meaningful notes from which to study after the class session is over. The questions that the instructor might ask, and the directions that the discussion may take, are similar to those described above under "Assignments." The difference is that the instructor has more control in a lecture format and that the students will encounter less frustration than they would if tackling the problem alone.

Examination Questions Is it appropriate to use errors in examination questions? The answer is yes—maybe. An examination is not the ideal place to introduce students to errors in problem formulation, but it is a good place to use such problems once they have been introduced in one of the other ways described above. Only during an examination can the instructor be fairly certain that students will read what they have been asked to read and think about it.

Projects It is probably impossible to develop a meaningful project assignment of any scope that does not contain some errors. And, in fact, this may be the most appropriate place for students to learn how to deal with errors. During a project students have time to think, explore, and try alternative solution methods. They need to be exposed to the realities and frustrations caused by engineering errors. The instructor must avoid formulating unrealistic or "trick" errors, however, lest the students view them as existing only in the pseudo-world of academia. Plenty of errors are inherent in most projects. The point is to deal with them as honest errors indicative of the real world of engineering.

DOES THE USE OF ERRORS WORK?

I have no statistically valid or quantitative data to show that using errors improves the quality of instruction. I do, however, have anecdotal evidence that it stimulates students and gives them a new and more realistic viewpoint of their profession. As to the effectiveness of this technique, I can only suggest that it is worth a try. I have found it successful.

In any case, errors certainly are a rich and exciting source of problems and examples that can stimulate lively classroom discussion. They can also provide a model of an engineer (the instructor) solving an ill-defined engineering problem in real time.

CONCLUSIONS

Honest errors appearing in textbooks, articles, and instructor-generated assignments can serve as meaningful vehicles of instruction. They demonstrate that engineering problems are often ill-posed, requiring frequent checks and creative problem-solving techniques. They thus help to prepare students for dealing with the many errors that they will inevitably encounter during their careers.

ACKNOWLEDGEMENT

I would like to thank all those authors whose errors I have used. The high quality of the texts that I use make these errors all the more meaningful and useful. I hope others will feel free to use errors that they find in my published work as classroom examples.

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ChE **book review**

AN INTRODUCTION TO NUMERICAL METHODS FOR CHEMICAL ENGINEERS

by J. B. Riggs
Texas Tech University Press, Box 4139, Lubbock, TX 79409-4139; $45 (cloth) (1988)

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The need for teaching a course in numerical techniques to undergraduate chemical engineers is being recognized more and more these days, and several schools have started offering such courses. As a result, a large number of textbooks have appeared in the area. However, only a few of them are addressed primarily to chemical engineering students. The book by Riggs is thus very timely, and it is an excellent text. A floppy disc containing several programs is also included. It can be used to solve problems in the text as well as being used later.

Chapter 1 of the book gives an introduction to matrix operations and round-off and trunction errors. Chapter 2 treats algebraic equations, and the method of LU decomposition for solving linear equations is of particular importance. Regula falsi and Newton's method are used for non-linear equations. The treatment in Chapter 3 of the various finite difference approximations of the first and second derivatives is good. This is followed by cubic spline interpolation, as well as quadratures.

Chapter 4 presents techniques for solving initial value problems (ODE's and PDE's) using both implicit and explicit methods. Several software packages have been referred to for solving stiff ODE's. The presentation of finite difference methods as applied to PDE's in space and time is excellent.

In Chapter 5 the finite difference approximations are suitably used to obtain the recursion (SOR) relations for the governing differential equation and for the boundary points, and these are combined to effect a numerical solution for a boundary--value problem. Also, good examples are given on direct methods using the Thomas algorithm and shooting methods. The use of a finite element library routine (FEC) is shown through an example.

Chapter 7 deals with regression analysis of experimental data. Very useful and common examples on chemical kinetics are presented and the use of optimization is shown for non-linear regression.

Chapter 8 discusses how the homotopy method can be used to find the roots of nonlinear algebraic equations. This chapter also discusses some more-advanced examples.

The most fascinating feature of the book is that several illustrations and problems from various fields of chemical engineering (mass transfer, kinetics, thermodynamics, etc.) are discussed. In some cases, the limitations of the techniques are clearly explained and the methods to overcome the difficulties are presented. For example, systems of nonlinear equations arising out of material balances on a CFSTR are solved by Newton's method (Chapter 2), but in the case of extreme non-linearity they are converted to coupled ODE's constituting an IVP, and these, in turn, are solved using a powerful algorithm (LSODE)

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