A CHOOSE/FOCUS/ANALYZE EXERCISE

In ChE Undergraduate Courses

G.K. Sureshkumar
Indian Institute of Technology • Bombay, Powai, Mumbai 400 076 India

Teaching methods involving only a lecture (or its variants) and a problem set format have several shortcomings.[1] For example, they neither promote the creativity[1-3] nor develop the independent thought processes that are desirable for a students' future endeavors in the "real world."

One of the strategies that has been widely discussed to partially offset the constraints of the lecture-problem set teaching method, is the use of open-ended problems. Such problems develop the important skill of divergent production[2] in students. Most open-ended problems, however, are limited by the instructor; for example, the creativity aspect is limited to finding various solutions to a particular, instructor-assigned (and thereby, instructor-limited) problem.

There are usually several students who are inherently more creative than the experience-honed instructor, and such an exercise does not fulfill the academic passions of those students. Also, for many students the concept of rational choice, which is crucial to success in the real world of industry or research, is not well developed. For example, based on questions posed to first-year students taking material and energy balances, we found that only 4 to 5 students in an 80$^+$-student class are clear as to why they chose chemical engineering as their major. This probably happens because most students come from well-protected family environments into a reasonably well-protected campus environment for their undergraduate studies, and they accept established hierarchies or trends without considering their own individual strengths or affinities.

To address these issues, a Choose/Focus/Analyze (CFA) exercise was conceived and given to students taking the first-year Material and Energy Balances course and the second-year Engineering Thermodynamics course for the past four years. A similar exercise (with minor variations in exercise philosophy) was also given to students taking courses with limited depth, such as Elements of Chemical Engineering (to non-chemical engineering students) and Bioprocess Principles, over the same period. This article discusses the CFA exercise along with summaries of some student exercises that this instructor found interesting.

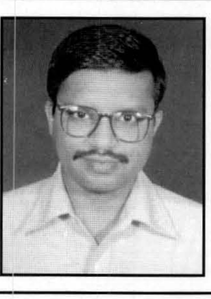
ASSIGNMENT

The following assignment was made during the discussion of the course-information material that was handed out to students on the first day of classes:

Problem Analysis: Students have to choose a problem of relevance to industry or any human endeavor and analyze it using the material and energy balance principles (or thermodynamics principles, for the thermodynamics course) learned in class. This is an open-ended problem that has been designed to improve the choice, focus, and analysis skills in students. The evaluation will be based on

Originality in approach	*15%*
Focus level	*15%*
Depth of analysis	*20%*
Quality of work	*20%*
Original contribution	*20%*
Presentation (mainly communication)	*10%*

A concise report (in the format that you think would best communicate your work) submitted a week before the last day of classes will be evaluated strictly based on the criteria given above. It will help if the problem is chosen well in advance (within the first four



G.K. Sureshkumar *is an Associate Professor in the Chemical Engineering Department and an Associate faculty member in the Biotechnology Center at the Indian Institute of Technology, Bombay. He received his BTech from the Indian Institute of Technology, Madras, and his PhD from Drexel University. His current research interests are mainly in free radical mediated optimal operation of bioreactors. Professor Sureshkumar can be contacted at <gksuresh@che.iitb.ernet.in>*

weeks) and sufficient time, distributed throughout the course's duration, is devoted to it.

Each student had to perform the exercise individually, and it carried either a 15% or a 20% weightage toward the final grade.

To make students self-reliant, the instructor offered help only when

- *The student decided to visit an industry. An introductory letter was provided in these cases, but the students were clearly informed that a letter alone would not guarantee their admission to the industry. The fact that more than 75 students over the past four years have managed to visit an industry for this exercise indicates their relevant abilities, either native or developed for this exercise.*
- *The student wanted to know if the problem was "too small" or "too large." The instructor would give his opinion on that aspect alone.*

The instructor was readily available, however, to clarify the other aspects of the course, such as class material, concepts, and problem sets.

This article discusses the Choose/ Focus/ Analyze exercise along with summaries of some student exercises that this instructor found interesting.

Students who thought of novel aspects to analyze were awarded high marks under the "originality in approach" heading, whereas the students who made good contributions, irrespective of whether the aspect was novel or not, were awarded high marks under the "original contribution" heading. Also, students who focused clearly on their task received high marks under the "focus level" heading, and students whose analysis had good depth scored high under the "depth of analysis" heading.

REPORT SAMPLES

Summaries of selected student exercises are presented in the following paragraphs. The report titles were those given by the students, with the student's name and the course title denoted below.

Fighting Alcoholism: A Chemical Aspect!

(Gaurav Tayal) (Material and Energy Balances)

This report demonstrated the use of material and energy balances to analyze a situation that is socially relevant. In his statement of motivation, Gaurav Tayal noted, "I have quite a few friends in my hostel [dorm] who can be classified as casual drinkers. What inspired me to undertake this exercise was the withdrawal symptoms that my friends suffer the next morning after drinking." He also conducted a short survey that he did among his friends in the hostel who drink, which showed that almost all the participants wanted control over their state the morning after. He clearly identified (focused on) the following aims for this exercise:

- *"What should be the maximum rate of intake of an alcoholic beverage of a given alcohol (C_2H_5OH) concentration so that it does not cause intoxication (hangovers occur only when intoxication sets in; otherwise the alcohol is easily metabolized by the body)?"*
- *"What should the relationship be between the rate of alcohol intake, the time period of drinking, the strength of the liquor, and the time taken by the body to revive?"*

To achieve the above aims, Gaurav represented the stomach, small intestine, and blood as control volumes, made suitable assumptions, consulted several books (including encyclopedias), performed material balances on ethanol, water, and total mass, and concluded

- *"To avoid intoxication, a normal person should drink beer at the rate of less than 790 ml h^{-1}."*
- *"To be in a position to drive home safely after a party, a normal person should drink less than 90 ml of whiskey over a two-hour period."*

While the actual numbers above may be subject to debate, the beauty in application of the material balance principles and the social relevance is clear.

Methyl Isocyanate Poisoning from Union Carbide Factory at Bhopal

(Sagnik Basuray) (Material and Energy Balances)

The motivation for this student was to see whether or not the biggest chemical factory disaster in India could have been avoided, using concepts that he had learned in his first chemical engineering course. It is well known that there were at least five levels of safety measures at the factory, including a flame tower to burn vented gases, all of which either failed or were not operational when the gas leak occurred. Sagnik performed material balance calculations on the relevant sections of the plant, which included tank No. 610 that leaked, and calculated the composition of the various streams for different inputs. Different inputs were considered to determine which inputs would have still averted the disaster. He also carried out energy balance calculations to conclude that even if the flame tower had been operational for burning away the released gas, it would have collapsed because it was structurally incapable of handling such a high rate of energy inflow as 1.05 MJ min^{-1}; therefore it was designed badly. Sagnik used the known civil engineering data on the tower to draw this conclusion.

From an instructor's viewpoint, a more refined analysis is needed before drawing such a strong conclusion, but the rudiments of good application are evident.

Thermodynamics of Breathing
(Narendra Dixit) (Engineering Thermodynamics)

Narendra Dixit wrote, "the process of breathing has always been a marvel to human intellect. It is something that goes on and on, sustaining life under the most critical of circumstances, stopping only when there is no more life.... It is an enlightening exercise to identify how much energy one spends (or consumes) to sustain one's own life."

His well-identified objectives were

- *To formulate a thermodynamic model of the respiratory apparatus*
- *To analyze the thermodynamics involved in the mechanism of breathing*

After referring to several medical and other books, he divided the process of breathing into two segments: a nasal process involving processes at the nose, and a post-nasal process involving processes in the lungs. He modeled the post-nasal breathing process as a cylinder with a frictionless piston with three openings for air, CO_2, and O_2. With suitable other assumptions, he determined that the total work done during each breathing cycle is a low 0.03 J, the entropy change is only 3.42×10^{-4} J K^{-1} per cycle, and the irreversibility is 0.1026 J per cycle. He concluded by marvelling at the superiority of natural mechanisms from a thermodynamic viewpoint.

Analysis of a Spirit Lamp Using Material Balances
(Gaurav Misra) (Material and Energy Balances)

The motivation for Gaurav Misra was his fascination with the simple spirit lamp. Based on material balance principles and certain assumptions (the limitations of which he was acutely aware of), he not only derived expressions to achieve the following objectives, but also suggested simple experiments to obtain numerical values of the relevant quantities. His objectives included

- *Obtaining an expression for the rate of flow of atmospheric air to the lamp*
- *Obtaining an expression for the rate of rise of fuel in the wick*
- *Obtaining an expression for the fuel efficiency of the lamp*
- *Relating the parameters of the wick with the efficiency of the lamp*

It is worthwhile to point out that the student had no exposure to fluid mechanics at the time and had to acquire some fluid mechanics principles from senior students and books to be able to attempt analysis of the relevant parts of his project.

Thermodynamic Analysis of Glass-Fiber Production
(Manoj Kumar Pandey) (Engineering Thermodynamics)

Manoj decided to apply thermodynamic principles to the glass-fiber production process. He focused on

- *Estimation of the power input required*
- *The effect of varying power input on viscosity (a narrow range in viscosities is required for good-quality fiber)*
- *Analysis of the cooling system and estimation of temperatures of the fiber exiting the nozzle*

He chose suitable control volumes for his analysis and estimated a power of 15 KW to produce about 10 Kg h^{-1} of fiber. He also found that the power input should be controlled to within less than 1% variation for good quality fiber and that the temperature of the fiber exiting the nozzle is 175°C.

Generation of Electrical Power Using Automobile Exhaust
(Prateek Jain) (Material and Energy Balances)

Prateek Jain considered a small dynamo at the end of a tailpipe to find out whether automobile exhaust can be used to generate electricity. He gathered background information on engines that use compressed natural gas as fuel, exhaust compositions, temperatures at exhaust, and other relevant information. Then he performed material and energy balances on the engine and tailpipe and found that the velocity of exhaust gases from the tailpipe could be used to drive a dynamo that could light a small bulb.

There have been many exercises that this instructor found interesting, although only a few are described above. The more common exercises included industrial data consistency checks using real data obtained from industry, material and energy balances, and exergy/irreversibility analysis in engineering thermodynamics.

STUDENT FEEDBACK

The above examples are good exercises, and it is obvious that the students thoroughly enjoyed the work. Over the past four years, an estimated 65% of the students expressed appreciation to the instructor for assigning this exercise because they felt they learned something useful. Two especially perceptive students thanked the instructor for not helping them at all, realizing that no help was the best path to learning. A few students who are currently graduate students pursuing their doctoral degrees in the U.S. have said that the CFA exercise is the only thing they still remember from the course after four years.

Except for five students (over the past four years), the rest of the students had no comments. Two of the five responding students said that the exercise was not useful to them, and the remaining three wanted the instructor to assign project titles. Among these five responses, three were received the first time the exercise was assigned and the other two were received the second time it was assigned. No adverse comments have been received since then. This indicates that the instructor perhaps became better at making the students appreciate the purpose of the exercise through mentioning it more often at appropriate junctures during the semester.

The class average in this exercise is usually around 65%, save for the first time it was given when it was 54.1%. This is probably because in subsequent years, copies of good reports from the previous years were made available as reference material.

VARIATION FOR COURSES WITH LIMITED DEPTH

The CFA exercise, in the form mentioned above, may not be suitable for courses with limited depth since they cover so many different principles in just a superficial manner. For such courses, the following exercise was assigned:

> *This exercise expects students to "adopt" a chemical (biochemical) industry by the third week of classes. Then, students should relate the principles taught in class to the actual processes taking place in the "adopted" industry and analyze, preferably, one aspect in detail. A concise report submitted a week before the last day of classes will be evaluated strictly on the following aspects:*

Link between fundamentals and actual processes	*40%*
Analysis of the actual process(es)	*30%*
"Reality" factor	*20%*
Presentation (mainly communication)	*10%*

If students visited the industry, they received the 20% "reality" factor. If they decided to perform a library exercise, then the closeness of their report to actuality formed the basis for marks on that aspect.

APPARENT CHALLENGES WITH THE EVALUATION ASPECTS

Although the instructor did not face any real difficulty with the evaluation except for the time needed to grade reports for large classes (five to six full days), some colleagues raised questions about certain evaluation aspects. It is worthwhile mentioning some of those apprehensions:

How can undergraduate students do independent work? The student exercises show that even first-year undergraduate students are capable of visiting an industry, independently, and choosing novel aspects for analysis when encouraged to do so.

How can you find out if a problem was taken from some unseen source? How do you judge originality? It is known that as long as grades are important, some students will cheat to get the highest possible grade.[4] However, the instructor usually knows the level of students' knowledge (at least on the imparted subject) in a class taught by him, and therefore he has a notional expectation. On that basis, if a report is suspicious, the instructor can have a one-on-one interview with the student. On the average, this instructor needed to interview approximately 20 students out of a 80^+-student class. By asking the correct questions, most of which are technical, it was easy to determine if the student had cheated. If just the problem was picked from some source and the analysis was done by the student, zeroes were given for the relevant aspects in the evaluation (such as originality in approach, focus level, and original contribution) so out of a possible 100 points, the student received marks in the thirties. This prevents cheating to a large extent in subsequent years because of the way the word spreads among the students.

The fact that no complaint/comments that someone got away with submitting "lifted material" have been received from an acutely grade-conscious set of undergraduates over the past four years, coupled with verbal comments that the instructor has been very fair, shows that it is possible to effectively weed out the cheaters.

ASPECTS OF THE LEARNING PROCESS

- **Course Fundamentals** It is the instructor's opinion that the students who scored above 50% (recall that the class average is usually around 65%) had picked up the course fundamentals to a desirable degree because they were able to view an aspect of their choice from, say, a material-and-energy-balances point of view.
- **Self-Reliance** Since the instructor denied any help at any stage of the project, students were forced to become self-reliant. It was initially difficult not to be nice to the students when they asked for help, but in the greater interest of the students, this instructor became accustomed to it.
- **Rational Choice** The students were asked to make a rational choice among the innumerable ways they could have approached the project and to be responsible for it. For example, if they did not obtain proper data from an industry and therefore had to change their project midway through it, they realized that they were completely responsible for choosing that particular industry in the first place.
- **Creativity/Lateral Thinking** A wide scope exists for exhibiting one's creativity in such an exercise because it invites the student to see all aspects from the point of view of the fundamental principles. Even when the student is not inherently creative, but desires to be creative, a significant amount of time (about half the semester) is provided to the student to apply himself toward that goal. In the instructor's judgment, about 20% of the students were creative through effort. Also,

creativity could be manifest in many aspects of the exercise, such as creative choosing, creative focusing, creative analysis, and creative presentation. Students who were creative were richly rewarded in the "originality in approach" and/or the "original contribution" categories of the evaluation. The exercise also provided good scope to exhibit lateral thinking, as demonstrated in some of the samples discussed in the earlier section. Some students also showed their "synthesis" abilities in their choice of the problem for analysis.

- **Focus** The focus level in almost 90% of the reports was acceptable, and in an estimated 60% of the reports it was good.
- **Communication and Professional Appearance of Reports** This exercise (deliberately) did not have a pre-determined format for reports in order to help the students think about how to present their work in an effective fashion. When a certain format is provided, it tends to curtail the freedom of organization, and in many cases, organization different from the traditional one is more effective in communication. The instructor estimates that about 80% of the class communicated their work reasonably well, and 50% of the class did it well (one reading was sufficient for understanding)—a fact that was surprising to the instructor in the first two years. Also, an estimated 60% of the reports had a very professional appearance. This indicates that when something is assigned as their responsibility, the students do a good job in ways not expected of them.
- **Helping Others** The students at I.I.T. Bombay are so highly competitive that on many occasions their "cut-throat" competition has saddened this instructor. In this particular exercise, however, it was a pleasant surprise to find classmates helping each other—be it in discussing possible ideas, sharing instructive web-site addresses, or teaching word-processing skills—while at the same time protecting their novel ideas. In their reports, many students acknowledged the help they received from their friends.
- **Teamwork** It is true that the CFA exercise does not promote teamwork, but the importance and value of teamwork is emphasized in tutorial sessions throughout the course. During the sessions (on the average, one hour per week, per course), the students are expected to work out problems given in the problem sets. Normally, teaching assistants grade the performance in the problem sets, which carries a 5% to 10% weightage toward the final grade. In the courses taught by this instructor, the class is divided into 10 to 15 groups of 5 to 6 students each. The problem sets are distributed about a week prior to the tutorial session, and the students are given complete freedom to discuss the problems with anyone. The only requirement is that they learn how to solve the problem. During the tutorial session, one student from a group, chosen by drawing lots, works out the problem on the board and is graded by the instructor for correctness in approach and answers to questions by the class/instructor (90%), and communication to the class (10%). Whatever marks the student earns are given to the entire group, thereby making the student responsible for the groups marks—or, in other words, the group is made responsible for each member knowing the solution. Ten percent weightage toward the final grade, coupled with the ignominy before their classmates if they do not prepare, are significant motivating factors for the majority of students to take the tutorials seriously. Thus, the importance of teamwork is emphasized.

From a broader perspective, Prausnitz[5] opined that chemical engineering is one of the humanities that has a deep human intent and that the role of context should be integrated into the chemical engineering curriculum rather than being delegated to a course in humanities. Felder[2] has said that if we are to produce engineers who can solve society's most pressing problems, we must somehow convey that problems in life are open-ended and convergent production (generation of the right answer to a well-defined problem), which is synonymous with academic excellence in engineering, is only one of the skills required. This instructor believes that the CFA exercise takes us a step closer toward realizing their suggestions.

ACKNOWLEDGMENTS

I thank the students of Material and Energy Balances (Introduction to Chemical Engineering), Thermodynamics, Elements of Chemical Engineering, and Bioprocess Principles classes that I have taught over the past four years for their enthusiastic participation in the CFA exercise. I also thank my colleague, Professor Raghunathan Rengasamy, for his suggestion to communicate this exercise as a paper to *Chemical Engineering Education.* In addition, I thank my colleagues, Professors Kartic Khilar and Hemant Nanavati for their input.

REFERENCES

1. Carlson, E.D., and A.P. Gast, "Animal Guts as Ideal Reactors: An Open-Ended Project for a Course in Kinetics and Reactor Design," *Chem. Eng. Ed.,* **32**, 24 (1998)
2. Felder, R.M., "Creativity in Engineering Education," *Chem. Eng. Ed.,* **22**, 120 (1988)
3. Prausnitz, J.M., "Towards Encouraging Creativity in Students," *Chem. Eng. Ed.,* **19**, 22 (1985)
4. Felder, R.M., "Cheating—An Ounce of Prevention,...Or the Tragic Tale of the Dying Grandmother," *Chem. Eng. Ed.,* **19**, 12 (1985)
5. Prausnitz, J.M., "Chemical Engineering and the Other Humanities," *Chem. Eng. Ed.,* **32**, 14 (1998) ❐