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A Choose – Focus – Analyze Exercise in Chemical Engineering Undergraduate Courses

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Abstract

To develop the skills of creativity, rational choice, focus, analysis and others in students, and also to make them appreciate the course material effectively, a Choose – Focus – Analyze (CFA) exercise was assigned to students taking Chemical Engineering undergraduate courses such as Material and Energy Balances and Engineering Thermodynamics, in the past four years. The need for the CFA exercise, the methodology and the outcomes, are discussed along with summaries of selected student exercises. A similar exercise for courses with limited depth is also discussed briefly.

Keywords: Creativity, Rational choice, Analysis, Chemical Engineering courses.

Motivation

Teaching methods involving only a lecture (or its variants) and problem set format have several shortcomings [1]. For example, they neither promote the creativity [1, 2, 3] nor do they develop the independent thought process that are desired in the future endeavors of students in the "real world".

One of the strategies that has been widely discussed to offset, partly, 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. However, most open-ended problems tend to have the limitation that they have been assigned by the instructor. Therefore, the creativity aspect becomes limited to finding various solutions to a particular, instructor assigned, and thereby, instructor limited, problem. Usually, there are 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 (as observed at the Indian Institute of Technology (I. I. T.), Bombay) the concept of rational choice, which is crucial to success in the "real world" (industry or research), is not well developed. For example, based on questions to the I year students taking Material and Energy Balances, it was found that, normally, only 4 to 5 students in a 80+ student class are clear why they chose Chemical Engineering as their major. This happens, probably because, most students come from well-protected family environments, into a reasonably well-protected campus environment for their undergraduate studies, that they accept established hierarchies or trends, without considering their individual strengths or likings.

To address the issues mentioned above, a Choose – Focus – Analyze (CFA) exercise was conceived and given to students taking the I (freshman) year Material and Energy Balances course and the II (sophomore) year Engineering Thermodynamics course, over the past four years. A similar exercise (with minor variations in exercise philosophy) was given also to students taking courses with limited depth such as Elements of Chemical Engineering (to non-Chemical Eng. students) and Bioprocess Principles, over the same period. This article discusses the CFA exercise along with summaries of some student exercises which this instructor found interesting.

Assignment

The following assignment was made during the discussion of the course information material which 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 which 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%*
Quantum 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 weeks) and sufficient time, distributed throughout the course duration, is devoted".

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

Further, to make students self-reliant, the instructor unequivocally denied any help, at any stage. The inputs from the instructor were strictly limited to two aspects, for this particular exercise:

1. if the student decided to visit an industry (visiting the industry was not necessary) then, an introductory letter was provided. But, the letter alone may not guarantee admission into an industry – a fact that was clearly stated to the students (the fact that more than 75 students over the past four years have managed to visit the industries for this exercise indicates their relevant abilities – native, or developed for this exercise)

2. after focusing on the problem for analysis, if the student desired to know whether the problem was 'too small' or 'too large', then the instructor would give his opinion on that aspect alone.

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

The students who thought of novel aspects to analyze were awarded high marks under the 'originality in approach' head, whereas, the students who made good contributions, irrespective of whether the aspect chosen was novel or not, were awarded high marks under the 'original contribution' head. Also, the students who had focussed clearly on their tasks for analysis received high marks under the 'focus level' head, and students whose analysis had good depth scored high under the 'depth of analysis' head.

Report Samples

Summaries of selected student exercises are presented next. The report titles were those given by the students, and, the names of students and the courses follow the titles.

1. Fighting Alcoholism, A Chemical Aspect!

(Gaurav Tayal) (Material and Energy Balances)

This report demonstrates the use of material and energy balances to analyze an aspect that is socially relevant.
As his motivation, Gaurav Tayal stated, "I have quite a few friends in my hostel (dorm) who may be classified under casual drinkers. What inspired me to undertake this exercise is the withdrawal symptoms that my friends show the next morning after drinking". He followed that up with results from a short survey that he did in his hostel among his friends who drink and showed that almost all the participants wanted to have a control on their state the morning after. Therefore, he clearly identified (focussed on) the 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, else alcohol is easily metabolized by the body).

- What should be the relation between the rate of intake of alcohol, time period of drinking, strength of the liquor and 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 (mainly) that:

- a normal person should drink beer at the rate of less than 790 ml h^{-1} to avoid intoxication

- a normal person should drink less than 90 ml of whiskey over a 2 hour period, if he should be in a position to drive back safely, after a party

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.

2. Methyl Isocyanate Poisoning From Union Carbide Factory at Bhopal

(Sagnik Basuray) (Material and Energy Balances)

The motivation for this student was to see whether the biggest Chemical factory disaster in India could have been avoided, using concepts that he learned in his first course in Chemical Engineering. 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 the tank No. 610 that leaked, and calculated the compositions of the various streams for different inputs. Different inputs were considered to determine which inputs would have still averted the disaster. Also, he carried out energy balance calculations to conclude that even if the flame tower had been operational to burn away the released gas, it would have collapsed because it was structurally incapable of handling such a huge rate of energy inflow of 1.05 MJ min^{-1}, and therefore, it was designed badly. Sagnik had 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 one can draw such a strong conclusion, but, the rudiments of good application, are evident.

3. 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 and stops only to find the man to live no more... 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, through the working of this model.

He referred to several medical and other books and he divided the process of breathing into two: 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.

4. 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, from a material balance perspective. Based on material balance principles and certain assumptions (the limitations of which he was acutely aware of), he had derived expressions to achieve the following objectives and had also suggested simple experiments to obtain numerical values of the relevant quantities. His objectives included:

- to obtain an expression for the rate of flow of atmospheric air to the lamp
- to obtain an expression for the rate of rise of fuel in the wick
- to obtain an expression for the fuel efficiency of the lamp
- to relate the parameters of the wick with the efficiency of the lamp

It is worthwhile pointing out that the student had no exposure to Fluid Mechanics at that stage, and that he acquired some Fluid Mechanics principles from senior students/books to be able to attempt analysis of the relevant parts.

5. Thermodynamic Analysis of Glass-fiber Production

(Manoj Kumar Pandey) (Engineering Thermodynamics)

Manoj decided to apply thermodynamic principles to the glass-fiber production process and focussed on:

- estimation of the power input required
- the effect of varying power input on viscosity, because 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 within less than 1% variation for good quality fiber and that the temperature of the fiber exiting the nozzle is 175^{o}C.

6. Generation of Electrical Power Using Automobile Exhaust

(Prateek Jain) (Material and Energy Balances)

Prateek Jain was interested in finding out whether the automobile exhaust can be used to generate electricity, by using a small dynamo at the end of the tail-pipe. He gathered the required 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 tail-pipe, and found that the velocity of exhaust gases at the tail-pipe could be used to drive a dynamo, which could light a small bulb.

There were many exercises which this instructor found interesting, although, only a few are given above to conserve space. However, the more common exercises from the students included industrial data consistency checks using real data obtained from the industry, in material and energy balances, and exergy/irreversibility analysis in engineering thermodynamics.

Student Feedback

The above are examples of good exercises and it is obvious that those students enjoyed the exercise, thoroughly. Regarding the others (over the past four years), an estimated 65% thanked the instructor for assigning this exercise, because they felt they learnt something useful. Two, especially perceptive, students thanked the instructor for not helping them at all, because they realized that helped them the best, to learn. One student expressed his happiness and appreciation in a poem. Also, a few students who are currently graduate students pursuing their doctoral degrees in the U.S., recently said that the CFA exercise is the only thing that they still clearly remember from the course, after four years. This is most probably because, they did it themselves, entirely, and as a consequence, learnt best. The remaining, except five students (over the past four years), did not have any comments. Two among the five students mentioned above opined that the exercise was not useful to them and the other 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, the second time it was assigned. No adverse comments were received after that. This indicates that the instructor became better at making the students appreciate the aims of the exercise, probably, through mentioning it a few more times, at appropriate junctures during the semester.

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

Variation of the Theme for Courses with Limited Depth

The CFA exercise, in the form mentioned above, may not be suitable for courses with limited depth, as they cover many different principles, in 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 got the 20 for "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 the time (5 to 6 full, consecutive days) needed to grade reports for large classes, some colleagues had raised questions on certain evaluation aspects. It is worthwhile mentioning a couple of those apprehensions here.

"How can undergraduate students do independent work?"

The student exercises show that even I year undergraduate students are capable of visiting the industries, independently, and choosing novel aspects for analysis, independently, if encouraged to do so.

"How can you find out if a problem was indeed 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 feels that it is easy to know the level of students (at least, in the subject imparted) in a class that is taught by him, and therefore, have a notional expectation. On that basis, if a report was indeed suspicious, the instructor had a one-on-one interview with the student, during the week when the reports were evaluated. On the average, the instructor needed to interview 20 students in a 80+ student class. By asking the correct questions, most of which are technical, on the project, it was easy to make the student admit whether he/she had cheated, because, we are not dealing with hardened criminals here. If blatant cheating did occur, a zero was given for the exercise. 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, original contribution and depth of analysis, so that the student received marks in the thirties out of 100. This prevents cheating to a large extent in the subsequent years because the word spreads around well in a residential campus.

The fact that no complaint/comment that somebody got away with submitting "lifted material", has been received from an acutely grade-conscious set of undergraduates at I.I.T. Bombay, over the past four years, coupled with the 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 had seen an aspect of their choice from, for eg., a material and energy balances point of view.

Self–reliance: As the instructor denied any help at any stage of the project, students became self–reliant. Initially, it was difficult not to be nice to the students when they asked for help, but, in the greater interest of the students, this instructor got 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 also 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, they realized that they were completely responsible for choosing that particular industry in the first place.

Creativity/lateral thinking: A wide scope exists to exhibit one's creativity in such an exercise because it invites the students to see any aspect from the point of view of the fundamental principles. Even if the student is not inherently creative, and desires to be creative, then a significant amount of time (about half the semester) is provided to the student to apply himself/herself towards that goal. In the instructor's judgement, about 20% of the students taught were creative through effort. Also, the 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 '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, and therefore, the exercise does not preclude 'synthesis' aspects, although, 'analysis' is an important aspect of the exercise.

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 the reports, so as to help students think about how to present their work in an effective fashion. If a certain format is provided, it tends to curtail the freedom of material organization, and in many cases, an 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 to understand), 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 if something is made "their baby", the students do a good job in aspects that one does not even expect them to.

Helping others: The students at I.I.T. Bombay are so highly competitive that, on many occasions, their 'cut-throat' competition had saddened the instructor. However, in this particular exercise, the instructor was pleasantly surprised to find the class-mates helping each other – be it in discussing possible ideas, sharing instructive web-site addresses or teaching word-processing skills, but, simultaneously protecting their novel ideas. Many students had acknowledged the help that they received from their friends, in their reports.

Team–work: It is true that the CFA exercise does not promote team-work explicitly. However, the importance of team-work was emphasized in the course through tutorial sessions. During the tutorial sessions at I.I.T. Bombay (on the average, one hour per week, per course), the students are expected to work out the problems given in the problem-sets (some instructors prefer to give the problem sets as homework exercises). Normally, the teaching assistants grade the performance in the problem sets, which carries a 5% to 10% weightage towards the final grade.

However, in the courses taught by this instructor, the class is divided into 10 to 15 groups of 5 to 6 students each, according to their roll number. 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 anybody. The only requirement is that they should finally 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, answers to questions by the class/instructor (90%), and communication to the class (10%). Whatever marks the student earns is given to the entire group, thereby, making the student responsible for the marks that the group gets, or, in other words, the group is made responsible for each member knowing the solution. Ten percent weightage towards the final grade coupled with the ignominy before their classmates if they do not prepare, and the responsibility for the entire group are significant motivating factors for the majority of the students to take the tutorials seriously, by their own admission. Thus, the importance of team-work is emphasized.

From a broader perspective, Prausnitz [5] opined that Chemical Engineering is one of the humanities which has a deep human intent and that the role of context should be integrated into the Chemical Engineering curriculum, rather than be delegated to a course in humanities. Felder [2] 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 towards realizing their suggestions.

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