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OPEN-ENDED PROBLEMS

34.1 INTRODUCTION

The educational literature provides frequent references to individuals, particularly engineers and scientists, that have different learning styles, and in order to successfully draw on these different styles, a variety of approaches can be employed. One such approach involves the use of open-ended problems.

The term "open-ended problem" has come to mean different things to different people. It basically describes an approach to the solution of a problem and/or situation for which there is usually not a unique solution. Three literature sources[1–3] provide sample problems that can be used when this educational tool is employed.

The authors of this book have applied this somewhat unique approach and has included numerous open-ended problems in several course offerings at Manhattan College. Student comments for the graduate course "Accident and Emergency Management" were recently tabulated. Student responses to the question "What aspects of this course were most beneficial to you?" are listed below:

1. "The open-ended questions gave engineers a creative license. We don't come across many of these opportunities."
2. "Open-ended questions allowed for candid discussions and viewpoints that the class may not have been otherwise exposed to."
3. "The open-ended questions gave us an opportunity to apply what we were learning in class with subjects we have already learned and gave us a better understanding of the course."

Fluid Flow for the Practicing Chemical Engineer. By J. Patrick Abulencia and Louis Theodore

4. "Much of the knowledge that was learned in this course is applicable to everyday situations and our professional lives."
5. "Open-ended problems made me sit down and research the problem to come up with ways to solve them."
6. "I thought the open-ended problems were inventive and made me think about problems in a better way."
7. "I felt that the open-ended problems were challenging. I, like most engineers, am more comfortable with quantitative problems than qualitative."

In effect, the approach requires teachers to ask questions, to not always accept things at face value, and to select a methodology that provides the most effective and efficient solution. Those who conquer this topic have taken the first step toward someday residing in an executive suite.

The remainder of this chapter addresses a host of topics involved with open-ended problems. The following sections are entitled: Developing Student's Power of Critical Thinking; Creativity; Brainstorming; Inquiring Minds; and Angels on a Pin. The chapter concludes with an applications section that contains eight open-ended Illustrative Examples primarily in the fluid-flow field.

34.2 DEVELOPING STUDENTS' POWER OF CRITICAL THINKING[4]

It has often been noted that we are living in the middle of an information revolution. For more than a decade, that revolution has had an effect on teaching and learning. Teachers are hard-pressed to keep up with the advances in their fields. Often their attempts to keep the students informed are limited by the difficulty of making new material available.

The basic need of both teacher and student is to have useful information readily accessible. Then comes the problem of how to use this information properly. The objectives of both teaching and studying such information are: to assure comprehension of the material and to integrate it with the basic tenets of the field it represents; and, to use comprehension of the material as a vehicle for critical thinking, reasoning, and effective argument.

Information is valueless unless it is put to use; otherwise it becomes mere data. To use information most effectively, it should be taken as an instrument for understanding. The process of this utilization works on a number of incremental levels. Information can be: absorbed; comprehended; discussed; argued in reasoned fashion; written about; and integrated with similar and contrasting information.

The development of critical and analytical thinking is the key to the understanding and use of information. It is what allows the student to discuss and argue points of opinion and points of fact. It is the basis for the student's formation of independent ideas. Once formed, these ideas can be written about and integrated with both similar and contrasting information.

34.3 CREATIVITY

Engineers bring mathematics and science to bear on practical problems, molding materials and harnessing technology for human benefit. Creativity is often a key component in this synthesis; it is the spark motivating efforts to devise solutions to novel problems, design new products, and improve existing practices. In the competitive marketplace, it is a crucial asset in the bid to win the race to build better machines, decrease product delivery times, and anticipate the needs of future generations.[5]

One of the keys to the success of an engineer or a scientist is to generate fresh approaches, processes and products, i.e., they need to be creative. Gibney[5] has detailed how some schools and institutions are attempting to use certain methods that essentially share the same objective: open students' minds to their own creative potential.

Gibney[5] provides information on "The Art of Problem Definition" developed by Rensselaer Polytechnic Institute. To stress critical thinking, they teach a seven step methodology for creative problem development. These steps are provided below:

1. Define the problem.
2. State objective.
3. Establish functions.
4. Develop specifications.
5. Generate multiple alternatives.
6. Evaluate alternatives.
7. Build.

In addition, Gibney[5] identified the phases of the creative process set forth by psychologists. They essentially break the process down into five basic stages:

1. Immersion.
2. Incubation.
3. Insight.
4. Evaluation.
5. Elaboration.

Psychologists have ultimately described the creative process as recursive. At any one of these stages, a person can double back, revise ideas, or gain new knowledge that reshapes his or her understanding. For this reason, being creative requires patience, discipline, and hard work.

Finally, Della Femina[6] recently outlined five "secrets" regarding the creative process:

1. Creativity is ageless.
2. You don't have to be Einstein.

3. Creativity is not an eight hour job.
4. Failure is the mother of all creativity.
5. Dead men don't create.

The reader is left with a thought from Theodore[7]: Creativity usually experiences a quick and quiet death in rooms that house conference tables.

34.4 BRAINSTORMING

Panitz[8] has demonstrated how brainstorming strategies can help engineering students generate an outpouring of ideas. Brainstorming guidelines include:

1. Carefully define the problem upfront.
2. Allow individuals to consider the problem before the group tackles it.
3. Create a comfortable environment.
4. Record all suggestions.
5. Appoint a group member to serve as a facilitator.
6. Keep brainstorming groups small.

A checklist for change was also provided, as detailed below:

1. Adapt.
2. Modify.
3. Magnify.
4. Minify.
5. Put to other uses.
6. Substitute.
7. Rearrange.
8. Reverse.
9. Combine.

34.5 INQUIRING MINDS

In an exceptional and well-written article by Lih[9] entitled *Inquiring Minds*, Lih commented on inquiring minds by saying "You can't transfer knowledge without them." His thoughts (which have been edited) on the inquiring or questioning process follow:

1. Inquiry is an attitude—a very important one when it comes to learning. It has a great deal to do with curiosity, dissatisfaction with the status quo, a desire to dig deeper, and having doubts about what one has been told.

2. Questioning often leads to believing—there is a saying that has been attributed to Confucius: "Tell me, I forget. Show me, I remember. Involve me, I understand." It might also be fair to add: "Answer me, I believe."
3. Effective inquiry requires determination to get to the bottom of things.
4. Effective inquiry requires wisdom and judgment. This is especially true for a long-range intellectual pursuit that is at the forefront of knowledge.
5. Inquiry is the key to successful life-long learning. If one masters the art of questioning, independent learning is a breeze.
6. Questioning is good for the questionee as well. It can help clarify issues, uncover holes in an argument, correct factual and/or conceptual errors, and eventually lead to a more thoughtful outcome.
7. Teachers and leaders should model the importance of inquiry. The teacher/leader must allow and encourage questions and demonstrate a personal thirst for knowledge.

Ultimately, the degree to which one succeeds (or fails) is based in part on one's state of mind or attitude. As President Lincoln once said: "Most people are about as happy as they make their minds to be." William James once wrote: "The greatest discovery of my generation is that human beings can alter their lives by altering their attitude of mind." So, no matter what one does, it is in the hand of that individual to make it a meaningful, pleasurable, and positive experience. This experience will ultimately bring success.

34.6 ANGELS ON A PIN[10]

There is a tale that appeared in print many years ago (there is some uncertainty regarding the source) that dissected the value of an open-ended approach to a particular problem. That story is presented below.

Some time ago I received a call from a colleague who asked if I would be the referee on the grading of an examination question. He was about to give a student a zero for his answer to a physics question, while the student claimed he should receive a perfect score and would if the system were not set up against the student: The instructor and the student agreed to submit this to an impartial arbiter, and I was selected.

I went to my colleague's office and read the examination question: "Show how it is possible to determine the height of a tall building with the aid of a barometer."

The student had answered: "Take a barometer to the top of the building, attach a long rope to it, lower the barometer to the street and then bring it up, measuring the length of the rope. The length of the rope is the height of the building."

I pointed out that the student really had a strong case for full credit since he had answered the question completely and correctly. On the other hand, if full credit was given, it could well contribute to a high grade for the student in his physics course. A high grade is supposed to certify competence in physics, but the answer did not confirm this. I suggested that the student have another try at answering the question I was not surprised that my colleague agreed, but I was surprised that the student did.

I gave the student six minutes to answer the question with the warning that the answer should show some knowledge of physics. At the end of five minutes, he had not written anything. I asked if he wished to give up, but he said no. He had many answers to this problem; he was just thinking of the best one. I excused myself for interrupting him and asked him to please go on. In the next minute, he dashed off his answer which read:

"Take the barometer to the top of the building and lean over the edge of the roof. Drop the barometer, timing its fall with a stopwatch. Then using the formula $S = 1/2\ at^2$, calculate the height of the building.

At this point, I asked my colleague if he would give up. He conceded and I gave the student almost full credit.

In leaving my colleague's office, I recalled that the student had said he had many other answers to the problem, so I asked him what they were. "Oh yes," said the student. "There are a great many ways of getting the height of a tall building with a barometer. For example, you could take the barometer out on a sunny day and measure the height of the barometer and the length of its shadow, and the length of the shadow of the building and by the use of a simple proportion, determine the height of the building."

"Fine," I asked. "And the others?"

"Yes," said the student. "There is a very basic measurement method that you will like. In this method you take the barometer and begin to walk up the stairs. As you climb the stairs, you mark off the length of the barometer along the wall. You then count the number of marks, and this will give you the height of the building in barometer units. A very direct method."

"Of course, if you want a more sophisticated method, you can tie the barometer to the end of a string, swing it as a pendulum, and determine the value of 'g' at the street level and at the top of the building. From the difference of the two values of 'g', the height of the building can be calculated."

Finally, he concluded, there are many other ways of solving the problem. "Probably the best," he said, "is to take the barometer to the basement and knock on the superintendent's door. When the superintendent answers, you speak to him as follows: "Mr. Superintendent, here I have a fine barometer. If you tell me the height of this building, I will give you this barometer."

At this point I asked the student if he really did know the conventional answer to this question. He admitted that he did, said that he was fed up with high school and college instructors trying to teach him how to think, using the "scientific method," and to explore the deep inner logic of the subject in a pedantic way, as is often done in the new mathematics, rather than teaching him the structure of the subject. With this in mind, he decided to revive scholasticism as an academic lark to challenge the Sputnik-panicked classrooms of America.

34.7 APPLICATIONS

Several of the open-ended Illustrative Examples have been drawn from the literature[1-2] and class notes from Theodore,[3] keying primarily on fluid flow issues.

Illustrative Example 34.1 You are asked to think of as many ways as possible to measure the viscosity of a fluid (consider both a gas and a liquid).

Solution Several types of equipment are available; they fall into five general categories:

1. Rotational type. This type measures the torque resulting from the rotation of a spindle inside a sample chamber through which the sample flows continuously.
2. Float or piston type. The float type measures the position of a specially shaped float inside a tapered tube through which the fluid flows at a constant rate. This equipment is similar to the rotameters used for flow measurement.
3. Time the discharge through a restriction, for example, an orifice or nozzle.
4. Time the fall of a ball (or obstacle) or rise of a bubble.
5. Capillary type. This type measures the pressure drop resulting from constant flow of the fluid through a capillary tube of specified diameter and length.

Because viscosity depends on temperature, the viscosity measurement must be thermostated with a heater or cooler.

Illustrative Example 34.2 Devise any method that involves the use of a "keftethe" (Greek version of an Italian meatball) to obtain the viscosity of a fluid.

Solution The simplest approach is to assume the "keftethe" can be physically modeled as a sphere. The sphere's terminal settling velocity in the fluid can be measured. By applying one of the particle dynamics equations developed in Chapter 23, the viscosity can be calculated if all physical property data is available. For example, if Stokes' law applies,

$$v = \frac{g\rho_p d_p^{\,2}}{18\mu}$$

can be rearranged and solved for μ

$$\mu = \frac{g\rho_p d_p^{\,2}}{18v}$$

Illustrative Example 34.3 A proposal plans to add fine particulates to a natural gas pipeline to reduce pressure drop. Comment on the value of the proposal.

Solution This a particularly interesting proposal. There is evidence that indicates that there is a reduction in pressure drop when fine particulates are added to a flowing fluid. Several research projects were initiated in this area in the 1980s and the data gathered verified the above statement. The proposal, however, has questionable merit because of the ultimate fate/disposal of the particulates. In effect, by "solving" one problem, another is being created. Specifically, the particles might not be combustible; if combustible, they might form harmful end products.

Illustrative Example 34.4 An undergraduate environmental engineering student has suggested that the kinetic energy of a moving gas stream normally discharged from a plant be recovered as part of an energy conservation measure. Comment on the idea.

Solution On the surface, this appears to be a project worthy of consideration. However, the energy content of a gas stream, even at extremely high velocities, possesses an insignificant (relatively speaking) amount of energy. For example, if 10,000 acfm (60°F, 1 atm) of a gas stream (that may be considered air) is discharged from a stack at 50 ft/s, its kinetic energy (KE) is:

$$\mathrm{KE} = \frac{1}{2}mv^2 = \frac{10{,}000}{379}\frac{(29)(50)^2}{32.2(60)}$$
$$= 1200\,\mathrm{ft}\cdot\mathrm{lb_f/s} = 2.0\,\mathrm{Btu/s}$$

This would not appear to be a cost-effective option for recovering energy.

Illustrative Example 34.5 List factors that need to be considered in selecting the pipe diameter for an underground Alaskan crude oil pipeline.[11]

Solution

1. *Temperature of the pipe and crude oil.* The temperature at which the crude oil must be kept at for the length of the run is important to selecting the material for the pipe and the diameter. The temperature also effects the tension on the pipe in expansion and contraction at different temperatures.
2. *Pressure.* The pressure throughout the length of the pipe is an important factor that diameter could greatly effect. Smaller diameters allow for lower pressures and larger diameters need larger operating pressures. The discharge pressure is the pressure at the end of the pipeline that is important to the design diameter and the length of the pipe.
3. *Velocity.* The desired velocity at which the crude oil will flow effects the pipe diameter and length since a smaller diameter is needed for higher velocities.
4. *Number of bends.* Bending in pipes greatly affects pressure throughout the pipeline and should be considered when choosing the pipe diameter. On a pipeline, there could be many bends that will effect discharge pressure and velocity.
5. *Surface finish.* The finish of the pipe surface effects the movement of the crude oil through the pipeline. Since crude oil is very viscous the surface finish could effect the velocity and pressure throughout the system. A smooth surface would decrease friction and allow a better flow.

6. *Total length of run.* Since the Alaskan pipeline will be very long, this is a key consideration in choosing a diameter that could hold up to harsh conditions. Throughout the length of the run there could be many bends and lifting of the pipeline that could damage the pipe and cause a leak. Therefore, the thickness of the pipe is very important.
7. *Pitching of pipe.* Pitching refers to whether the pipe is lifted above ground at different areas. This results in straining of the pipe and velocity changes. Therefore, a diameter that can withstand pitching is also a factor.
8. *Climate.* Permafrost is defined as any rock or soil material that has remained below 32°F for more than two years. Warm permafrost remains just below 32°F. Therefore, any additional heat will cause thawing, which in turn could lower the stability of the soil.
9. *Slope.* The pipeline should (if possible) gradually slope downward to reduce the chance of particles settling out of the crude oil, which could eventually clog the pipe.
10. *Earthquake protection.* Due to certain faults that the pipeline will cross, there must be an earthquake monitoring and protection system in place for the pipeline.
11. *Properties of oil.* Oil pumped out from different sites has different physical as well as chemical properties. For example, if the oil contains a lot of impurities, the pipe is more likely to get corroded and hence proper coating will be required to prevent corrosion. Zinc coating is commonly used for Alaskan crude oil pipelines. Another physical property is the viscosity of oil that is being pumped. In addition, the denser the oil, the greater will be the pressure and thus the pipe size will need to be larger.

Illustrative Example 34.6 A ventilation system in a laboratory is no longer capable of pulling the required air flow to properly prevent toxic fumes from escaping work hoods. Rather than purchase a new fan to increase the flow rate, suggest other solutions to the problem.

Solution

1. Reduce the generation of the fumes.
2. Reduce the pressure drop across the valves, piping, etc., of the system.
3. Increase the opening (if possible) of the hood to reduce the pressure drop.
4. Provide another exhaust.

Illustrative Example 34.7 A cooling water pump is no longer capable of delivering the required flow rate to a highly exothermic reactor. Rather than purchase a new pump, you have been asked to list and/or describe what steps can be taken to resolve the problem.

Solution The obvious option is to replace the pump. Since that is not a viable option, other options can include:

1. Carefully check the pump, including the clogging of screens and/or intakes, impellers.
2. Increase pipe size(s), that is, the diameter.
3. Decrease pipe length.
4. Eliminate unimportant valves, expansion and contraction joints, etc., in order to reduce the pressure drop.
5. Decrease the viscosity of the water by increasing its temperature.
6. Use a different cooling medium altogether or add an "additive" to the cooling water to decrease the viscosity and/or increase the heat capacity of the cooling medium.
7. Create an endothermic side reaction in the system.
8. Use synthetic lubricants to reduce friction.

Illustrative Example 34.8[12] During the heat of the space race in the 1960s, the U.S. National Aeronautics and Space Administration (NASA) decided it needed a ball point pen to write in the zero gravity confines of its space capsules. Prepare a solution to the problem.

Solution Since the gravity is zero, a pressure force is needed to force the ink to flow out. A simple device to solve the problem is provided in Fig. 34.1.

When the screw moves, ink will be transferred to the edge of the ball point.

Figure 34.1 Zero gravity pen.

After considerable research and development, the "Astronaut Pen" was developed at a cost of $1 million. The pen worked and also enjoyed some modest success as a novelty item back here on Earth. The Soviet Union, faced with the same problem, used a pencil.

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