Hands-on Projects to Engage Non-engineering Students

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Abstract

Three hands-on projects intended to engage the non-engineering student in environmental issues are introduced and discussed. In the first, students use different sized agar cubes with a diffusing dye to observe how surface area to volume relationships affect mass transfer rates. Results can be used to introduce students to issues such as cellular diffusion, air stripping towers, trickling filters, and aeration processes. The second project investigates the effectiveness of toilet paper as a barrier to *Escherichia coli*. By working with a culture of *E. coli*, students learn that toilet paper is not always an effective barrier between microorganisms and skin. Results can lead to discussions on pathogens, sanitary issues and the spreading of disease, indicator organisms, and wastewater treatment processes. In the third project, students create a closed population of yeast cells and watch the population rise exponentially until it crashes several days later. Comparisons to the Earth as a closed and/or open system can follow, along with a discussion of population growth models, carrying capacity, population control, and other ethical issues.

Introduction

Multidisciplinary! Whether in engineering or a non-technical career, multidisciplinary describes today's workplace. For engineers this may mean working on a team of other engineers with different specialties. Often times, however, it involves working with, or relating technical information to, people with little or no technical background. For example, an engineer may be asked to give a presentation at a public meeting or may work with the business department regarding the economics of a particular project. As a result, engineering curriculums across the country are striving to prepare their graduates to better meet these challenges. But is it enough to work within the engineering community? As evidenced by this session whose objective is to reach out to non-engineering/non-college populations, many believe it is not. Such is the case at Valparaiso University where the Lilly Foundation has funded the development of a new course which has been designed to promote interchange between engineering faculty and liberal arts students as well as to help non-engineering majors better understand the importance and relevance of technology in our society. The objective of the course is to increase the awareness and understanding that political science majors have with respect to the interrelationship between the environment, technology, and providing an increasing human population with an adequate standard of living. It also seeks to provide political science majors with the tools needed to make decisions regarding technical issues and the environment that will best serve society. In meeting these objectives this course well help prepare a part of the work force for the multidisciplinary aspects that will almost certainly be encountered.

In an attempt to engage the non-engineering students in the issues at hand, small labs and/or hands-on projects were performed as part of the class. These labs were intended to encourage faculty-student contact, cooperation among students, and active learning, all of which are included in the *Seven Principles for Good Practice in Undergraduate Education* [1]. Research has also shown that the retention of material by students is much higher when the student is directly involved in the learning process. This involves engaging the students in the learning process rather than just transferring facts. In other words, students learn by doing, not by merely listening. More specifically, Astin [2] studied 159 colleges and universities. In the process he investigated and monitored eighty-eight environmental factors to determine their relationship to the student's academic achievement and personal satisfaction with post-secondary education. The two environmental factors found to be most influential were interaction between students and students, and interaction between students and faculty, both of which were especially stressed in these projects. This paper presents the procedure for three such projects and, to encourage further classroom discussion, discusses how the concepts involved are linked to other technological, environmental, and societal issues.

Diffusion and Surface Area to Volume Ratios Project

Diffusion governs the natural world. Whether it's the intricate design of villi in your small intestine, the alveoli deep within your lungs, or a trickling filter designed by an engineer to treat contaminated water, the entire rational for the design is based on optimizing transfer rates by maximizing surface area to volume ratios. Millions of villi, for instance, coat our small intestines and project about one millimeter from the surface. With approximately ten to forty villi per square millimeter, and a typical small intestine length of 6.35 m and diameter of 2.5 cm [3], the average person has from five to twenty million villi coating the inside of their small intestine. The villi help to provide an estimated 200 m^2 of surface area within the small intestine [4] which allows our digestive system to efficiently absorb nutrients and transport them to our blood for our use and nourishment. Alveoli, the tiny air sacs in our lungs, provide the same increase in surface area, but allow our lungs to absorb oxygen and de-sorb carbon dioxide in the relatively small volume contained within our chest cavity. It has been estimated that the lungs contain over 300 million alveoli, providing a surface area of over 70 m^2 [3]. By discussing these issues with students, they will understand not only the importance of diffusion and surface area but also that our very existence depends on them.

Many engineering designs mimic the designs discussed above. This project is intended to allow students to see first hand just how important surface area to volume ratios are to diffusion limiting processes. Once this has been achieved the concepts involved can be integrated into a discussion of its relevance to environmental engineering designs such as bubbling aeration systems, trickling filters, rotating biological contactors, air strippers, and even wastewater treatment plants. Materials needed are shown in Table 1 below.

Table 1. Materials for Diffusion and Surface Area to Volume Ratio Project [5]

Safety goggles	150 mL 0.1% NaOH
Ruler	Paper towels
Plastic spoon	Plastic gloves
Lab aprons	3 cm x 3 cm x 3 cm block of phenolphthalein agar
Finger bowl	Plastic knife

Procedure

In this lab students place three phenolphthalein agar cubes of different sizes (1, 2, and 3 cm on a side) in a finger bowl and cover them with 0.1% NaOH. The NaOH is allowed to diffuse into the cubes for ten minutes before the cubes are removed and dried. The cubes are then cut in half and the depth of diffusion of the NaOH into each cube is measured and recorded. For the full procedure please see *BSCS Biology* [5]

Discussion

As the NaOH diffuses into the agar it combines with the phenolphthalein turning it pink such as shown in Figure 1. Thus the distance the NaOH has diffused into each agar block can be directly measured. Discussion of this phenomenon is almost limitless but can include the following questions:

a. Calculate the volume of each cube and list the cubes in order of volume, from largest to smallest. Calculate the surface area of each cube and list the cubes in order of surface area to volume ratio, from largest to smallest. How does the list compare?
b. Why are the smaller cubes much more red than the larger cubes?
c. How long do you think it would take the larger cubes to become completely red? What assumptions did you make in your estimate?
d. Estimate the surface area to volume ratio of a single cell that is not more than 0.01 cm on a side. What role does diffusion play in determining cell size? How does this affect the operation of a wastewater treatment plant?
e. For a bubbling aeration system, what would be more effective, large or small bubbles? Is there a limit as to how small or large the bubbles should be?
f. Is oxygen the only substance diffusing in a bubbling aeration system? What other substances are present? When might it be desired to minimize diffusion rates?

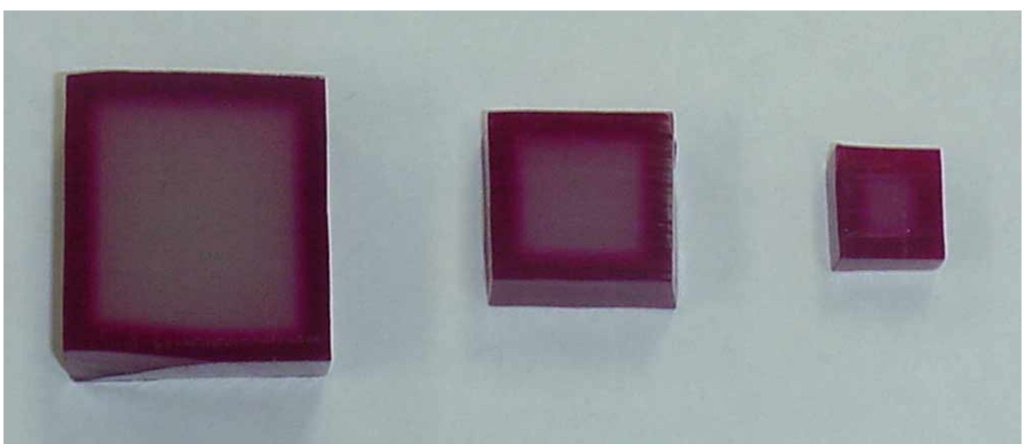

Figure 1. Typical Results for Diffusion and Surface Area to Volume Ratios Project
Effectiveness of Toilet Paper Project

Moms and Dads say it all the time "Wash your hands!" Many know practicing this simple sanitation method is important after using a restroom and/or before eating, but is washing your hands always adequate? Perhaps even more thought provoking is the question "Does toilet paper provide an effective barrier between pathogens and our skin?" By answering these questions with this project students deal with issues they encounter several times a day, yet most do not thoughtfully consider the issues and their consequences. Furthermore, these issues can lead to more discussion on pathogens and wastewater treatment processes, sanitation and the spreading of disease, and indicator organisms. Materials needed are shown in Table 2 below.

Table 2. Materials for the Effectiveness of Toilet Paper Project [6]

EMB agar	Rubber gloves
Safety goggles	Lab coats
Nutrient and plain agar	10% Bleach solution
Nutrient broth	Disposable petri dishes
E. Coli culture	Toilet paper

Procedure [6]

1. Wearing rubber gloves, pour the *E. Coli* culture on a sterile nutrient agar plate covering the surface. Let stand for ten minutes. Pour off E. coli culture into container designated by your instructor. The surface of the agar now simulates a specimen of moist feces.
2. Wearing rubber gloves, cover your fingers with your toilet paper sample in a manner similar to regular use. Rub your toilet paper covered fingers over the agar to simulate normal use.
3. Discard the toilet paper into the 10% bleach solution.
4. Gently rub your fingers on one half of a second sterile nutrient agar plate.
5. Wash your gloved hands as you normally would do after using the restroom and dry on a towel.
6. Rub your washed fingers over the second half of the second sterile nutrient agar plate.
7. Incubate at 30^{o}C for 24 hours.
8. Inspect the plates for colony forming units.
9. Discard all materials in 10% bleach solution.

Discussion

Often times many more colony forming units will form on the half of the agar plate that was exposed to the unwashed hand as compared to the washed hand. Typical results are shown in Figure 2 in which the left side of each petri dish was exposed to an unwashed hand while the right side was exposed to a washed hand. While not shown in Figure 2, some plates may exhibit colony forming units on the washed side of the petri dish. The following questions can lead to a discussion on scientific methods and issues involved in environmental engineering.

a. Is toilet paper an effective barrier to fecal pathogens and is washing hands always effective? What assumptions are you making in answering this question based on the experimental results?

b. How do the results of different toilet paper brands and/or differing the number of layers of toilet paper used compare to each other?
c. What other pathogens may be present in a wastewater sample? Can we assume that if no *E. Coli* forms on the agar plate there are no other pathogens present?
d. Compared to other microorganisms, what characteristics should an indicator organism exhibit?
e. How could a treatment process be designed to kill pathogens? How could a treatment process be designed to physically remove pathogens and why might physical removal be desired?

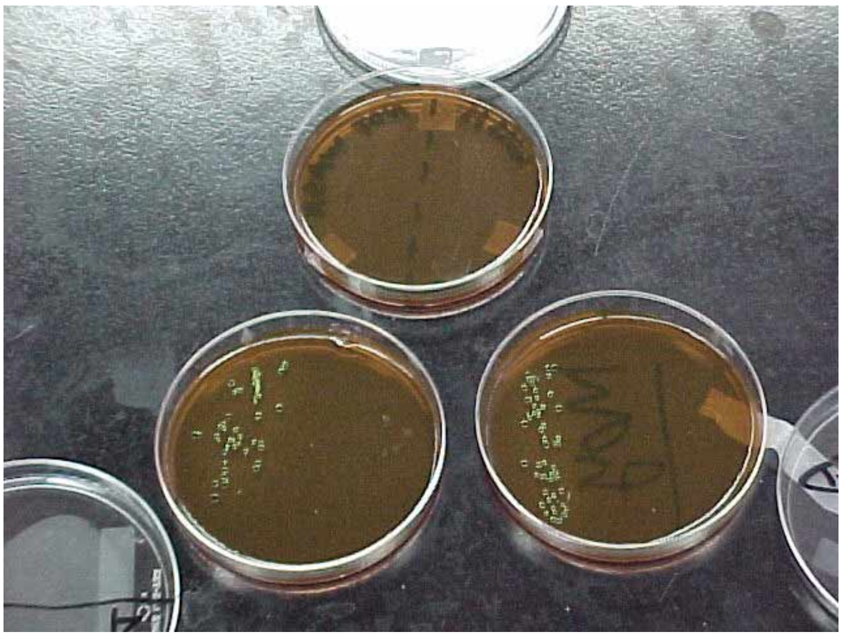

Figure 2. Typical Results of Effectiveness of Toilet Paper Project

Population Growth Project

As the world's population continues to grow and parts of the world get more and more crowded, the effects of the increase are often difficult to ignore. These effects, some argue, are mostly positive; more jobs, more consumers, and a stronger economy. Others argue that we are rapidly depleting our natural resources and that the Earth has some maximum population carrying capacity which it can support. This latter argument supports the notion of a naturally occurring population cycle within each nation. In this cycle, the population continually fluctuates around the natural carrying capacity, P_1 in Figure 3a [7]. The population eventually increases above P_1 and reaches some over populated state at P_2. In time, through some emergency situation such as a crop failure, the population is reduced to P_1, and the cycle continues.

If however, the argument continues, through humanitarian efforts or through technology such as genetic engineering of crops, the food supply is continually increased in every emergency situation, the population will continue to increase well beyond P_2 as shown in Figure 3b. Some argue that technology will allow these increases to continue without end while others argue the

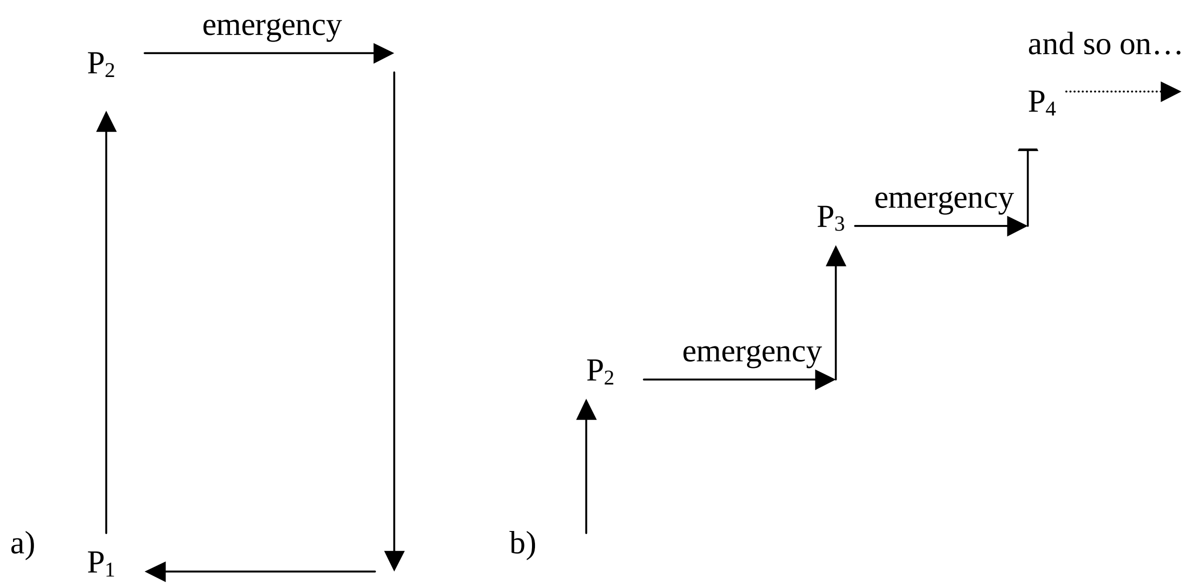

Figure 3. a) Typical Population cycle for a nation with no outside aid or increase in food supply and b) for a nation with food source being supplemented or increased during emergencies.

population will ultimately be reduced to near zero by some total collapse. Which argument is correct? What role do engineers play in sustaining the worlds increasing population? In developed nations environmental engineers have used technology not only to support increasing populations but have also increased the length and quality of life by providing a safe drinking water supply and effective wastewater treatment. On the other hand, advancements in technology such as the combustion engine have lead to the pollution of our environment. Another pertinent question therefore is "Is technology the problem or the solution?" This project, which involves examining the population growth of yeast cells in a closed system, can lead to a discussion of these and other challenging issues. Materials needed for this project are listed in Table 3 below.

Table 3. Materials for the Population Growth Project [5]

Safety goggles	Rubber gloves
Turbidimeter	Microscope
Screw cap test tubes	Ruler
Ruled microscope slides	Grease pencil
1 mL graduated pipet	Yeast
Sabouraud dextrose powder	Distilled water
Autoclave	Sugar
Package of dry yeast	

Procedure

Again, the step-by-step procedure, which may be found in BSCS Biology [5], is summarized here. In this lab each student or group of students receives two test tubes that contain 10 mL sterile nutrient broth solution per tube. 0.1 mL of yeast stock solution (as prepared by the instructor) is added to one of the two test tubes and the yeast population in each test tube is monitored for one week. The yeast population in each test tube and/or class average values are plotted as a function of time on semi-log paper.

Discussion

The yeast population generally increases exponentially but ultimately crashes. In some cases, after an initial crash the population may rise slightly before experiencing another crash to near zero. This slight rise may be attributed to yeast cells metabolizing the dead yeast cells in a form of cannibalism. Also, it should be noted that dead yeast cells, if counted, could partially mask the true magnitude of the population crash. A discussion of the issues mentioned above can develop by asking the following questions.

a. Is the Earth a closed or open system?
b. What could have been done to prevent the crash of the yeast population? Can the population crash really be prevented or just delayed?
c. How does the Earth's population compare to the yeast population? Is there an upper limit to the human population the Earth can support?
d. Have there been instances of human population crashes in the past? How long will it be before we see a decrease in the human population and what factors might cause the decrease?
e. What can we do to prevent (or delay) a future population crash? Should we do anything? Are there ethical limitations on what we should or shouldn't do?
f. What must be done in order for us to live sustainably? Would these methods be effective if not instituted worldwide? How could these methods be initiated worldwide?

Conclusion

Across the country engineering departments have begun to make a significant effort to reach out to students of non-technical majors and non-college populations. Whether these efforts are in the cast as a semester long course, day long seminar, or some other form, retention can be increased and discussions can become more active when the participants are engaged in hands-on projects. Three such projects (along with possible discussion questions) are presented. The projects demonstrate to the participant's concepts that are inherent in environmental engineering and can lead to a discussion of technical, ethical, and societal issues.

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