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Often in a study of the cell and its cellular processes such as photosynthesis, respiration, assimilation, and growth, biology students find it difficult to acquire an adequate idea of how these living processes interact. Synthesis of these separate processes into an organized whole is even more difficult to comprehend. This paper describes an analogy between a factory and the cell that has been found effective as a classroom discussion technique to more clearly illustrate what the cell must do to maintain itself and to divide.

The technique is best used at the conclusion of a unit on cells and their basic activities. A convenient way to use the analogy is to spend some time at the end of a class period introducing the factory and its objectives. The following class period the factory is designed in more detail and the analogies are drawn between the factory and the cell. The device is described as it has been used in teaching high school biology. No attempt is made to point out the many variations which could be devised to suit varying circumstances or the scholastic level of the students.

The class discussion is begun by having the students design together a hypothetical factory building. (It is better to design the physical aspects of the factory building before any explanation is begun to avoid an overly simple structure such as a roofless, windowless adobe hut.) Sketches of the factory are simply noted on the chalk board as various characteristics are described. The general features of the building such as type of framework, outer covering, windows, foundation, etc., are decided upon and outlined. The type of energy source (coal, oil, etc.) to be utilized in the factory is chosen.

Next, an outline of the objectives of the factory must be made. It must be made clear at the onset that the factory will have to be able to produce another factory just like itself. Raw materials will be provided but the factory must process all of these materials and fabricate all of the components for the new structure.

The next segment of the discussion is to consider together in more detail what raw materials the factory would need, how they will be processed, and what other capabilities the factory must possess. This segment may be a bit bewildering to the students with no mechanical background; however, no single process has to be pursued in great detail.

At this point the discussion can take various directions. Since no proposed factory is likely to be just like another, no two discussions will be entirely alike. If the factory building

framework is of steel beams the factory must receive, among other things, iron ore, limestone, and coal as raw materials. The limestone must be crushed and the coal transformed to coke before smelting can take place. Thus the factory must have, and be able to produce, a stone crusher, an oven to produce coke, and conveyors to handle the materials. Obviously, steel will be needed for gears, pulleys, shafts, and sheeting in addition to the framework beams. If the factory is planned as a wooden structure, saws, nails, hammers, and such materials will be required. Again steel will be needed. If glass windows are planned by the architects, quartz, lime and soda, together with a furnace, are a necessity.

Next the energy requirements must be considered. If coal is to provide the source of energy, a steam engine or a boiler, turbine, and generator will be necessary. Transmission of the energy to various parts of the factory will require a system of shafts, pulleys, and belts, or electric wires and motors. As additional equipment needs are determined, the variety of capabilities the factory must possess are increased. Obviously the discussion could continue for many class periods just working out the many details of these capabilities, but a few illustrations will suffice to indicate the magnitude of what the factory in itself must produce.

Another aspect of discussion to be emphasized is that specifications and directions must be available for every part and process which is included in the factory. These must be in the form of blueprints, specifications, etc., which of course must be duplicated to supply the new factory. This again will present more problems for the factory for it must now manufacture paper, fountain pens and ink, or typewriters, or pencils. It should be pointed out that the factory cannot produce another like itself if no directions for procedure are available. It is essential that the ability to produce another factory must be included in the new factory also.

Finally, this section of the discussion is summarized by describing the fabrication of new machines and parts, the construction of additions to the building to accommodate the new machinery, and the distribution of components so that each end of the factory has at least one of every component. The climax is the building of two walls through the middle of the factory separating it into two independent units. One factory has produced a duplicate of itself.

The second phase of this teaching technique involves drawing an analogy between the factory just described and the cell. A green alga or a hypothetical "typical" cell containing chloroplasts serves very well. Questioning the students can bring out the fact that the cell's raw materials are carbon dioxide and water plus various minerals, and its source of energy is light. Instead of mechanical or electrical energy transmission, chemical energy is transported to all parts of the cell in the form of ATP (adenosine triphosphate) or PNH (reduced phosphopuridine nucleotide). Mitochondria and chloroplasts serve as generating stations for these chemical energy carriers. Several cellular components serve as machines; enzymes are able to take apart or put together or

rearrange molecules, ribosomes construct new protein molecules to serve as enzymes, membrane components, or in other ways. Instead of having blueprints and specifications, the cell stores information in DNA (desoxyribose nucleic acid) molecules. Instead of engineers and foremen, cells use RNA (ribose nucleic acid) to translate DNA information into action.

Other similarities between cells and our factory can be pointed out. Machinery often breaks down and has to be repaired or replaced, so do enzymes and ribosomes and other cell parts. Unrepairable machinery must be removed just as damaged cell components are broken down and resynthesized or respired. Factories have waste products which must be removed or the factory will cease to function, just as a cell dies when it is poisoned by waste products. We might violate the rules a bit to permit the factory to obtain certain parts or products already formed, just as cells might obtain certain vitamins or essential amino acids from their environment. Another interesting possibility is that mistakes might be made in duplicating the instructions for the new factory. This would result in some slight change, perhaps the size of a bolt or the length of a shaft. This might be inconsequential, but would probably be detrimental to a specific process and might prevent the production of a part which would lead in turn to the inability of the factory to completely duplicate itself. Once in a great while this mistake might produce a beneficial effect allowing the factory to operate more efficiently. Point mutation in cells are also perhaps "mistakes" with much the same consequences. The effects of deletions or inversions or repetitions might also be mentioned.

To finally drive home the point of the enormity of the problems cells face in living and reproducing, have the students imagine that the factory runs automatically, completely without workers. Computers preparing punched cards, or tapes which direct everything that goes on in the factory might accomplish this. Feedback, detecting, and coordinating mechanisms similar to those found in cells would be involved. When one attempts to comprehend the complexity of this system a new respect and understanding of the cell and its living processes is gained.

BOOK REVIEW

BIOLOGY, ITS PRINCIPLES AND IMPLICATIONS Garrett Hardin (Second Edition)

The author presents a modern introduction to the science of biology. The use of the unifying concepts of molecular biology and ecology integrates the subject matter. Biology is presented in an intellectually exciting manner through use of implications and humor. Through the use of problems and their solutions, the student is encouraged to test his understanding and ability to think critically.

The better student would benefit most from the use of this text since it is based upon his reading level and ability to answer questions.

The author draws from Scientific American Offprints for additional readings as well as other texts.