Using the Analogical Systems Approach to Teaching Biological Engineering

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What is it that distinguishes biological engineering from other branches of engineering? When asking this question about any engineering field, a number of types of responses can be returned. Some engineering fields are distinguished by particular applications, such as agriculture or mining. Such fields tend not to have a distinguishing knowledge base. Other engineering fields are based on particular sciences, such as mechanics or electricity. These fields have usually developed consistent sets of technological methods appropriate to their fields, for example applied mathematics in electrical engineering and unit operations in chemical engineering. Such methods allow the study of the subject matter in rather generic form to give the ability to apply the imparted engineering knowledge to applications not completely known beforehand.

If biological engineering is to successfully evolve into a branch of engineering dealing with the entire field of biology, with all its diversity, methods must also be developed to characterize biological systems in generic terms. These methods should emphasize the similarities among diverse biological organisms and systems. For example, biological systems metabolize substrates, move, reproduce, require space, respond to external stimuli, have positive entropy, and so on. Biological engineers taught to expect these common characteristics will be able to deal with biological systems on familiar terms, no matter what the specific application. This is the analogical systems approach that possibly could become the unique method in biological engineering.

In the report by Garrett et al. (1992), one particular core course exemplified this approach. The course entitled "Biosystems Responses to Environmental Stimuli" is intended to be a black-box engineering study of the quintessential aspects of biological systems. To be successful, this course should not be taught considering specific biological systems (for example: humans, animals, plants, microbes, and others). Rather, the course should teach common aspects of locomotion, metabolism, toxicity, temperature, etc. Specific examples can show how particular species conform or not to the general expectations given for biological systems.

To a lesser extent, control in biological systems, and engineering properties of biological systems can also follow the analogical systems approach. In control, biological organisms usually display feedback techniques during learning, open-loop or feed forward techniques for habitual operations, and optimization during times of stress. A controls course given to biological engineers should stress these common approaches used by diverse biological organisms. Likewise, properties should be taught from a general viewpoint, rather than dwell particularly on many specific cases.

The transport processes of fluid flow, heat transfer, and mass transfer (and also electrical flow, information transfer, and such biological actions such as locomotion, eating, etc.) are important in biology and should be understood by biological engineers. The analogical systems approach lends itself to study of this subject matter so well that it can be generalized to fields other than biological engineering.

To use the systems approach, one must develop facility with the ability to conceptualize a problem in the standard means we have shown in this chapter. It helps to be able to conceptualize in terms of electrical symbols, because these are both succinct and thoroughly defined, but is not necessary as long as the symbolic concepts are well-defined. Each symbol used must be "pure," in the sense that resistance, capacity, and inertia are not mixed together in a way that makes it difficult to translate the symbolic form into mathematical form. Done correctly, this step is trivial, and the problem can be solved easily . . . Johnson (1997).

There are common elements to all transport processes that students should become familiar with. There are two kinds of variables, effort and flow, and two kinds of sources that correspond to these variables. Effort variables cause actions to occur; flow variables are the effects of the effort variables. Examples of effort variables are force, pressure, temperature, concentration, and voltage. Examples of corresponding flow variables are velocity, volume flow rate, heat, mass flow rate, and electrical current.

We have seen that there are some commonalities among transport processes. Each has at least one effort variable and one flow variable. There are the physical properties of resistance, capacity, and inertia that are defined in terms of appropriate effort and flow variables. Various balances can be written in terms of these effort and flow variables in order to apply the general concepts to specific cases.

Students should learn the differences between ideal effort sources and ideal flow sources. There is a great deal of difference between a constant temperature and a constant heat flow. The first is appropriate for an isothermal condition on a wall; the second is appropriate for sunlight streaming in a window.

One relationship between effort and flow variables is resistance, defined as the ratio of effort to flow. Resistance limits flow from an effort source; it has no effect on a flow source. Resistance dissipates energy or power coming from a source.

Another relationship is capacity, which stores flow and maintains effort. Capacity is the ratio of the time integral of flow to effort. Capacity is present in many transport systems.

Inertia is the ratio of effort to the time derivative of flow. Inertia maintains flow. Many transport systems have no appreciable inertia.

Systems Diagram in Ecology. *Draw the systems diagram and give the systems equation for a large herd of caribou migrating through a constrictive narrow valley.*

Solution:

The valley can be represented by a resistance that regulates the flow of animals. On the downstream side of the valley, the caribou are presumed to migrate freely without significant impediment. We can thus represent the downstream side as a connection to the zero potential for the effort variable, which is migratory pressure.

Representation of the upstream side of the valley could be one of three possibilities:

1) *A capacity element. Using this element would signify that the number of migrating animals is finite, whatever could be stored in the capacity element. Flow of animals from the element would decrease as the migratory pressure, and the number of animals upstream, decreases.*

2) *A pressure source. Using this element would signify that the migratory pressure of animals attempting to move through the valley does not decrease with the passage of animals. However, the constriction of the valley still has an effect on the flow of animals through it.*

3) *A flow source. Use of this element would mean that flow of animals would be constant, and not affected by the resistance represented by the valley.*

Of these three, the flow source is clearly wrong. We know that a more restrictive valley would slow the flow of animals. There are some properties of the capacity element and the pressure source that make each of these at least partially correct. The capacity element represents the fact that the number of animals is finite; the pressure source, however, indicates that the flow of migrating animals is not likely to decrease over time (except, perhaps, for the very last animals). The best choice for a representation of the upstream side of the valley is thus the pressure source. The systems diagram for caribou passing through a restrictive valley thus appears in Figure 1.9.1; the systems equation, after equation 1.7.76 is:

$flow = N = p_s/R_v$

Transient responses of systems can be characterized by time constants if the responses are exponential with time, or by natural frequency if the response is oscillatory. The time constant for a system dominated by resistance and capacity is calculated as the product of these two. If the system is dominated by resistance and inertia, the time constant equals inertia divided by resistance. A system dominated by capacity and inertia will be oscillatory.

Spread of Diseases. *New strains of Asian flu often begin in China, where genes are exchanged between Avian influenza viruses indigenous to ducks and mammalian influenza viruses hosted by pigs. Define effort and flow variables, draw the systems diagram, and give the systems equation for the spread of Asian flu around the world. What factors do you think could be important in the determination of values for various systems parameters?*

It is important for students to know the full meanings of each of these elements, because conceptual solutions to transport problems start with proper choice and placement of these elements. Once the systems diagram for a solution has been drawn, the remainder is detail: how to calculate element values, how to combine elements, and how to calculate resulting effort or flow variables of interest. Providing the systems context gives a framework in which calculation details can be placed, thus reducing confusion about what detail is important, and when.

Fluids flow through conduits due to a pressure gradient along the conduits. The effort variable is thus pressure difference and the flow variable is the flowing fluid. Height differences can be considered to be a second effort variable in fluid flow. While pressure in a fluid sometimes depends upon the height of fluid above it, there are instances, such as due to the action of a pump or due to a container with elastic walls, where pressure and fluid height do not correspond. Thus, pressure and fluid height are linked, but to consider these two to be separate effort variables is sometimes instructive.

Biological systems exhibit sources, resistances, capacities, and, sometimes, inertia. Replacing the biological system with its equivalent systems elements reduces the biological problem to a generic concept that can be treated in generalized fashion.

References

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