AC 2011-747: SYSTEM THINKING FOR EVERYBODY

Yumin Zhang, Southeast Missouri State University

(Fisher) Yumin Zhang Assistant Professor Department of Physics and Engineering Physics Southeast Missouri State University Phone: (573) 651-2391 E-mail: ymzhang@semo.edu Web: http://www.physics.semo.edu/

David K. Probst, Southeast Missouri State University

David Probst is a Professor in the Department of Physics and Engineering Physics at Southeast Missouri State University. He regularly teaches an upper-level interdisciplinary course invovling both majors and non-majors.

System Thinking for Everybody

Abstract

System theory was originated in the field of engineering, and now it is widely used in many different fields, such as in biology and economics. However, in most universities the courses on system theory are still limited to the college of engineering. In order to make it available to all students, we propose to open a university wide course as part of the interdisciplinary components of our general education program. As the students taking this course come from different majors, the topics we discuss are also from different fields, such as physical system, engineering system, chemical system, biological system, ecological system, economic system and social system. By learning this course, students can realize that there is a common thread cross-cutting all these different fields. Therefore, they will be able to analyze problems with a wide perspective in the future.

I. Introduction

Modern science and technology was developed in the social background of industrialization, where division of labor was the most important feature. As the frontier of research began to broaden, a division of labor also occurred in the scientific and engineering communities. Such an approach has also penetrated into the education system where students are forced to confine themselves into a certain discipline. Although this may benefit the depth of knowledge in a certain area, the growing trend of over-specialization has brought about a serious problem: Students often develop career type tunnel vision in a specific direction and are blind sighted to other related areas.

As pointed out by Barry Richmond[1], the whole society needs to change the way to think and solve problems. For example, little progress has been achieved for a number of social problems despite decades of painstaking efforts, such as poverty and drug addiction. In addition, the way we act to solve certain problems often makes them even worse, such as the treatment of certain diseases and the war of anti-terrorist. On the other hand, these issues can be addressed effectively, if system thinking is widely adopted[2].

In our university, broad and balanced education is emphasized, where students are required to take 51 credit hours of general education courses, which cover a broad spectrum of knowledge under three perspectives: natural systems, human institutions and individual expressions. In addition, students must take three interdisciplinary courses that integrate knowledge from two or three of the categories within or across these perspectives. As system thinking is widely employed in both natural and social systems, we think that a course on system thinking can be offered to all the students.

One of the barriers in learning system theory is the requirement of advanced mathematics. Although not a big problem for students majoring in science and engineering, it is a great challenge for students in other majors. Fortunately, there are software packages available to bridge this gap in mathematic skills, such as STELLA®/iThink® . With the help of this software, all students can learn system thinking and apply it to their own area of study.

This is a three credit hour course, and there are two one-hour lectures and one two-hour lab each week. The objectives of this course include the following: 1) have a better understanding of the physical world and human society; 2) develop skills on information gathering and analysis; 3) understand the behaviors of systems at different levels; 4) learn how to take actions to achieve expected results; 5) provide an opportunity for open-ended and creative investigation; 6) develop written and oral communication skills in reporting and presenting scientific results.

Most students taking this course are junior and senior students, who have already learned the basic courses on math, science, economy and social institutions. When the basic concepts and theories are introduced at the beginning, there will be homework assignments, and students can use the simulation software STELLA®/iThink® to simulation the behavior of simple systems. After students learned how to set up system models and do the simulation, six levels of systems will be introduced, which will be discussed in detail below. Among these six topics, students will choose one of them to investigate in depth. As students are from different majors, they can choose the system they are most familiar with. First they need to gather useful information, and then set up their system model to simulate its behavior. Two or three students can work as a group, and they can collaborate and improve the model they created. After completing the simulation and verification, they need to write a project report and present the result to the whole class. Besides, students are also required to write four essays on the remaining five kinds of systems. In these essays students need to review the concepts and theories, and include at least one application.

II. Course Outline

The first part of this course is an introduction to the basic concepts of system thinking. First, *stock* and *flow* are introduced as the basic elements in a dynamic system. Stock can be considered as a container, and then flow is the flux of water coming into or leaving it. A pressing current issue in US is the national debt (stock), which will keep increasing if the annual deficit (flow) is not properly addressed. The mathematical relationship between these two quantities is straightforward: Stock is equal to the time integral of flow, and flow is equal to the derivative of stock. On the other hand, this analysis can also help students to better understand these concepts in calculus.

Second, positive and negative feedback will happen in a system that is connected into a loop, which is ubiquitous in almost all the complicated systems. An example of negative feedback is the thermostat for room temperature control, and chain reaction can be considered as an example of positive feedback. Such a simple feedback loop can be formed readily in the system diagram above by setting the flow under the control of the stock through a function.

Mathematics is the indispensible tool in analyzing dynamic systems. Due to the diverse background of the students in this course, we will avoid the advanced mathematics. Fortunately, many important phenomena can be modeled with simple relationships. The simplest one is the linear function, and the result is also straight forward: exponential increase or decrease. In fact, exponential increase cannot last very long, and eventually other nonlinear factors will kick in. Therefore, a more practical model is a quadratic relationship, which will lead to limit cycle and logistic map. Many systems can be modeled by logistic map, such as the population of certain species supported by their environment. Actually any growth is subjected to certain limits[3], ignoring this fact will often cause a tragic debacle from overgrowth.

The second part of this course is an introduction to the simulation software STELLA®/iThink® . Human beings are intelligent, but computers are much better in doing logic and arithmetic operations. Therefore, a computer loaded with software is an invaluable tool in the investigation of dynamic system behaviors. For example, an interesting issue is the time delay between demand and supply. It seems harmless at the first look, but it turns out to be a potential cause for oscillation or even instability, which is reflected as the periodic cycles of boom and bust in economy. This problem is pretty hard to analyze except with advanced knowledge of system thinking. However, it can be conveniently simulated and analyzed with the help of STELLA®/iThink® .

The third part of this course is the investigation of systems in different fields. The first topic is a physical system, where a simple climate model can be set up. The inflow of energy from the sun is assumed to be constant, and the outflow of energy by radiation is affected by the concentration of greenhouse gasses, as well as the surface temperature of the earth. With this simple model students can investigate the climate change by simulating the temperature variation. One can also add more factors into the problem, such as plants and ice cap on the surface of the earth.

The second topic is an engineering system, and a simple mass-damper-spring system will be analyzed. One of the applications of such a model is an automobile's suspension system; students can understand how it works by this analysis. There are three key parameters in this system: displacement, velocity and acceleration. The relationships of the three players can be described by two first order differential equations. Without the damper, the result will be a harmonic oscillation, as the energy cannot be dissipated. If the damper is put into place, the amplitude of the oscillation will attenuate gradually. Students can change the stiffness of the spring and the magnitude of the damper, and they can investigate the effects by simulation.

The third topic is a chemical system, and chemical clock will be analyzed as an example[4]. There are several different chemical reactions to implement such a clock, but all of them belong to the category of autocatalytic reactions. The key feature is a feedback mechanism, and the product of one reaction becomes a reactant in another action. As a result, the rate equations for autocatalytic reactions are fundamentally nonlinear, which can bring about a limit cycle. Therefore, the concentration of the chemicals will oscillate at a certain frequency, which is often associated with a periodic change of color.

A biological system can be considered as a special case of chemical systems, and a model of neuron will be used as an example. There are four different ions involved for its operation, but we can limit ourselves to a simplified model with just two: sodium and potassium[5]. In this way, we can set up just two stock-flow diagrams for these ions and a function of the electric potential. Students can investigate the firing patterns of the neurons at different conditions.

The fourth topic is an ecological system, and a simple predator and prey system will be analyzed. We can assume there are only two species of animals living on grassland: sheep and wolf. In this model there are two stock-flow subsystems, and they are mutually affected. If the population of sheep is very high, the population of wolf will increase, as there is sufficient food supply. On the other hand, if the population of the wolf is very high, the population of sheep will decrease. Students can investigate the evolution of these populations by adjusting the relationships between these two species, as well as the carrying capacity of the grassland.

The fifth topic is an economic system, and a model of competitive equilibrium will be analyzed. The key concepts here are supply and demand, and both of them contribute to and are also affected by the price. In a simplified model there are one stock and two flows for supply and demand, respectively. The price will be a function of the level of the stock, and it will affect the flows of supply and demand. On the other hand, a reference price is provided, which is the equilibrium value when the supply and demand is balanced. Students can investigate how the price will change when there is an imbalance at the beginning, and how time delay will cause oscillation of the price[6].

The sixth topic is a social system, and urban sprawl can be studied as an example. An urban area is a complicated system, where physical, social, economic, ecological, environmental, infrastructure and institutional subsystems are involved and interrelated. Urban sprawl is related to both the functionality of these subsystems and their relationships to one another. There are mainly three controlling parameters: population, connectivity, and functions. Therefore, a simplified model can be set up and investigated by simulation.

III. Assessment

We will use a pretest and posttest to measure the improvement in system thinking of students. The test consists of asking students to suggest solutions to problems presented in case studies that are best addressed by considering the interrelationship of the issues involved rather than only considering superficial approaches. A rubric will be developed to guide scoring the tests. Over time, the assessment instrument would be improved, and the validity and reliability of it established.

IV. Conclusion

We believe that students from every major will benefit from system thinking, and it can be of great help in solving many persistent social problems. Therefore, we are proposing a course on system thinking for the general education curriculum. Fortunately, our university offers such a platform, so we decided to take this opportunity to offer a course on system thinking that is open to all the students in our university. With the help of a software package, students without much background in science and engineering will be able to study and investigate system behavior on a wide variety of topics. This course will be initially offered in fall semester of 2011.

Reference

1. Barry Richmond, *An Introduction to Systems Thinking*, isee systems, 2004.

2. Jay Forrester, "Counterintuitive Behavior of Social Systems", *Technology Review*, Vol. 73, No. 3, Jan. 1971, pp. 52-68.

3. Donella Meadows, Jorgen Randers, and Dennis Meadows, *Limits to Growth: The 30-Year Update*, 3rd ed. Chelsea Green, 2004.

4. Bruce Hannon and Matthias Ruth, *Dynamics Modeling*, 2nd ed., Springer, 2001

5. Eugene Izhikevich, *Dynamical Systems in Neuroscience*, MIT Press, 2007.

6. John Sterman, *Business Dynamics: Systems Thinking and modeling for a Complex World*, McGraw-Hill, 2000.