Ecological Modelling 373 (2018) 13–21

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Teaching systems thinking to general education[1] students

George E. Mobus

Emeritus Computer Science & Systems, Computer Engineering & Systems, Institute of Technology, University of Washington Tacoma,1900 Commerce St., Tacoma, WA 98402-3100, United States

A R T I C L E I N F O

Keywords[2]:
Systems thinking
Naïve learners
System dynamics
Food production model
Problem and project-based learning

A B S T R A C T

Under the proposition that all college students are able to learn to think in more systemic ways, and understand the value of systems modeling for assisting their thinking, I designed a course for freshmen with no more than basic algebra. In this course the students were exposed to basic systems concepts with a focus on system dynamics modeling (using Donella Meadows' *Thinking in Systems*) of a permaculture-based food production system. They were given a basic problem: How much land area would be needed to collect enough solar energy in food plant photosynthesis per year to feed a community of fifty vegetarians? They were told that the farm would be in the Seattle WA, USA area so they could find the average monthly insolation values. Several additional rate constants and conversion factors were provided so they could build a spreadsheet-based model to generate the number of calories needed.

This paper provides anecdotal evidence that systems theory naïve students were able to successfully build a model (in teams) but also were able to apply systems thinking to aspects of their own lives as demonstrated in essays (individuals). Many students reported "seeing the world differently" as a result of the course, particularly seeing how different aspects of the world are connected through various relations. As a result of these successes the course was upgraded to be a little more advanced for upper division students.

1. Introduction

Systems thinking has been defined differently by different authors but almost always indirectly, even when the term "thinking" is used explicitly (Churchman, 1968; Meadows, 2008; von Bertalanffy, 1969; Weinberg, 2001). Many writers in the field of systems science seem to assume that there is a cognitive process (thinking) that is somehow better or at least enhanced by the content of thought being "systems" (for an exception see, Checkland, 1999, 3–4). All authors, of course, go on to define what a system is, that is what constitutes the conceptual framework of systemness, and leave it to the readers' imagination as to what systems thinking actually is. All are convinced that once a person grasps the essence of systemness, they will embark on a new kind of thinking in which they will see the world differently. In my experience in teaching systems science to what I will call naïve students, i.e. those who had never been exposed to the concept of systemness previously, I have to conclude that those writers were correct. Over the last decade, in teaching systems principles and methodologies to general studies students (those who are non-science majors seeking university distribution credits in science) and to students explicitly studying computer science and engineering, at levels from entering freshmen to graduate students in a Master's program, I have observed the majority of these students undergo a distinct change in their modes of thinking about the world and even their own lives.

Rather than follow in the footsteps of my predecessor writers on this subject I want to provide a definition of systems thinking that will serve as a basis for making observations of students thinking modes and their evolution throughout the course. These observations are pre-scientific to be certain, made casually but, I hope, with some scientific insights. They may provide a basis for developing a more rigorous approach to the field of education in systems science.

Systems thinking, then, is the cognitive ability of a person to perceive wholeness of a 'thing',[3] to perceive the connections between the 'thing' and other things with which it interacts causally, and to perceive

E-mail address: gmobus@uw.edu.

[1] 'General education' is a term applied to curricula that may be required of first-year college students in which they are required to take courses in liberal arts and a variety of sciences and math to ensure that the students enter a major field of study with more broadly applicable thinking and communication skills. See Wikipedia: https://en.wikipedia.org/wiki/Curriculum#United_States_2 for background. Accessed 12/18/2017.

[2] Problem-Project-based Learning - PPBL, a pedagogy for active learning.

[3] The word "thing" is one of the most useful nouns in English. Similar words, serving the same purposes, are found in most other languages. It serves as a placeholder for designating an object or relation between two objects prior to specifying what the thing is. That such a word seems to exist in so many (if not all) languages suggests that the brain has a kind of template for systemness that is innate.

https://doi.org/10.1016/j.ecolmodel.2018.01.013
Received 1 September 2017; Received in revised form 15 January 2018; Accepted 22 January 2018
0304-3800/

the internal composition of sub-things, themselves interconnected and interacting to produce the thing itself. They are able to see systems in the world and how those systems are connected more broadly. But moreover, they are able to see how the systems are organized for purposes and how, if they fail to serve those purposes, they will not be able to persist as systems. Finally, it means that a person is able to use knowledge of systems to reason about the future states of the world based on those systems behaviors.

It should be clear from this description/definition that much thinking fits in this model. That is to say, human beings naturally think in modes that reflect some implicit systemness, even if only subconsciously (c.f. Arsenault and Buchsbaum, 2015; Huth et al., 2012 re: representations; Mobus and Anderson, 2016 re: language of thought or systemese; Mobus, 1994 re: causal modeling in the brain). Were it otherwise, the world, which is a system of systems, would be unintelligible. However, the kind of systems thinking that most writers refer to is explicit or conscious systems thinking. That is, a person is consciously aware of the web of connections that link components together to make a system, they are aware of the causal nature of the dynamics of components and how that results in the behavior of the whole, and so on.

The significant difference between subconscious and conscious systems thinking is that the former is more-or-less taken for granted ("that is just common sense"), whereas the latter results in one becoming aware of non-obvious aspects of a system that are part of systemness but not always immediately perceptible. For example, many complex systems, like an organization, have fuzzy boundaries that have to be inferred from understanding how systems interface with their environments – something that can only be obtained through explicit understanding of boundary properties.

Thus, the proposition for teaching systems science, i.e. explicit systems thinking, is that it enables students to achieve greater reasoning power about the real systems they encounter because they have an explicit template for the patterns that must exist in those systems regardless of the specific medium (i.e. biological, social, or ecological) embedding those systems.

2. Background

2.1. Course description

- Name: *Introduction to Systems Science*
- Credit Hours: 5 quarter hours [class meets for 4 h each week with significant outside assignments]
- Class size: 20–30

This course was designed with a summer stipend grant from the Milgard School of Business, Center for Leadership and Social Responsibility: Faculty Innovation Support. It was designed as a problem and project-based course wherein lectures are kept to a minimum and the students learn by doing (see Section 3.1). The author had been teaching systems science in various other courses for general education and drew upon that experience to construct a course suitable for a wide audience.

The course, as described in this paper, has been taught for four years as both a 1st year required core course and as a service course for students needing science credits.

2.2. Student profiles

Students who took these courses ranged from liberal arts majors to environmental and computer science & engineering. They also ranged from entering freshmen through seniors in undergraduate programs. A more advanced form of the course was offered to graduate students in a Master's of Computer Science program.

Most of the undergraduate students, especially the lower division students, came into the course with fairly weak mathematical maturity, not an uncommon factor today. Most had some kind of lab-based science in high school or as freshmen in college. However, I discovered early on that their retention of what they had been exposed to was nil. For example, most had some biology courses, but when probed to recall how DNA is transcribed to messenger RNA and that providing the basis for protein synthesis, the most common response could be summarized as: "I remember we talked about that, but I don't remember the details.[4]" In other words, many of the students taking these courses were profoundly ignorant when it came to any depth in science or math.

The basic course design was developed with three different student profiles in mind. The first involved entering 1st-year students who were required to take a series of "core" courses covering various university requirements in general education (i.e. natural science, math, social science, and humanities). The University had designed the 1st-year courses to give students an orientation experience that was to include interdisciplinary approaches to the general education subjects.

The second group of students were mostly upper division students who needed additional science credits toward the university requirements. In this course, I assumed that students would already be oriented to university level work so added some greater depth to some of the topics.

A final group was composed of master's level graduate students in computer science. In this course, I added a great deal more work in computer simulation development. Rather than using a spreadsheet to implement models, these students were required to write the programs in languages like C++ or Java. In this article I will only be discussing the undergraduate versions of the courses, with particular attention on the 1st-year version as the change from naïve to informed thinker was most dramatic in this group.

2.3. Learning objectives

The students were exposed to many aspects of systems science and systems thinking. I set forth a few learning objectives that they could achieve that I could assess through their problem-solving, project accomplishment and exams. These were:

1. Identify the major attributes of systemness in everyday encounters with real world systems
2. Construct several kinds of models of relatively simple systems in the real world, i.e. conceptual as well as dynamical
3. Become able to interpret graphs generated by system dynamics models and reason about the underlying causes of behavior

3. Pedagogy

3.1. Problem- and project-based learning

The main form of pedagogy used in these courses has been based on a combination of problem- and project-based learning (PPBL).[5] Both of these methods are used, often separately, and described differently, but both involve active learning by students in small groups (teams) where the objective is for the students to produce artifacts (e.g. reports, models, or computer programs) that answer particular requirements. In both methods, the students are given an objective (e.g. a problem to solve or a larger research/development project) in which they must discover ways to approach solutions under the watchful eyes of the teacher (who acts as a coach and guide but does not provide specific

[4] This is, in fact, one of the most common statements I hear in teaching computer science courses that have several prerequisite courses in which concepts and skills are meant to be retained for the later courses.

[5] These methods are well explained in Wikipedia articles, https://en.wikipedia.org/wiki/Problem-based_learning and https://en.wikipedia.org/wiki/Project-based_learning. Accessed 7/02/2017.