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Integrating Systems Dynamics into a Course on Sustainability: A Model-based Reasoning Approach

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The Science of Engineering is an undergraduate course for non-science majors. In the course, students are introduced to key concepts about sustainable engineering and development, in which individuals use mathematics and scientific knowledge to analyze real world environmental problems, and propose solutions which are eco-friendly, equitable, and cost-effective.

The course combines environmental concepts with information technology concepts in a format designed for non-technical majors. This responds to a growing trend to integrate information technology principles and concepts into the broader higher education curriculum. Many institutions require not only basic computer literacy, but also that students have demonstrated competency with information technology in specific disciplinary contexts.

In order for this type of course to be more than an academic exercise, however, students must find the curriculum to be relevant and applicable to their everyday experience. Toward this end, an undergraduate course was redesigned to provide opportunities for non-science majors to conceptualize global issues and environmental concepts in terms that can be comprehended on a more personal, experiential level. System Dynamics modeling has been instrumental in the approach to redesign.

Course Themes
The issues of using renewable energy sources in combating world pollution constitute one key theme of this course. Another major strand includes the trends and effects overpopulation, and how unchecked population growth affects the long-term survival or collapse of entire ecosystems.

The course includes two specific curricula innovations that result from collaborations among Computing and Information Technology and Engineering faculty.
The first includes the design and use of a mobile power generation and storage unit. Dubbed TREPS, the (Transportable Renewable Energy Power Station), the project is housed within a van that includes photovoltaic panels used to store electrical energy for use at a mobile site, and to transfer surplus electrical energy to the power grid. More recently, a wind turbine for collecting energy and converting it to utility compliant electrical energy. has been added to the types of renewable energies sources that students study and model in the class.

Secondly, over-population and pollution are studied as key factors to model when consider issues of global survival. The course utilizes Believing Cassandra: An Optimist Looks at a Pessimist's World (AtKisson,1999), as a main textbook. The book uses systems thinking concepts and versions of the World3 models (Meadows, Meadows, & Randers, 1992) as a major source of its arguments about the need for sustainable development, and provides a basis for developing a debate topic and students' abilities to reason from scientific data.

During their study of overpopulation and sustainable development in this course, students use STELLA or Vensim simulation software to model the effects of trends such as exponential growth and overshoot and collapse on population ecosystems over time. Using the system dynamics modeling software, students can vary the parameters of the variables, and alter the model to add new variables to the existing model.

Why Modeling?

Thinking and learning about science is generally thought of as based on two fundamental activities: first, theory-building and second, experimentation or theory testing. Modeling can make a valuable contribution in both areas. Each of these issues is addressed in an effort to help students create meaningful mental models of these problems and the complex variables that impact the problem over time.

Most of our mental models of such problems exist tacitly as a worldview or a set of beliefs and assumptions of which we are seldom consciously aware in normal cognitive processes. Therefore, using a simulation modeling mechanism that externalizes our assumptions and beliefs about how the world operates contributes an important first step in providing a way for us and others to begin examining those conceptions or misconceptions.

For instance, Lehrer and Schauble (2000) have identified practices that show promise for developing model-based reasoning. The authors point out that models are capable of making forms of student reasoning open to investigation by teachers and other students. This provides valuable feedback about student learning and misconceptions that can inform teaching decisions and practice.

In addition, simulation software such as STELLA or Vensim provides an opportunity that is not possible in the real world: the ability to compress time and simulate the changes that cannot be conducted as actual experiments. In addition, simulation software makes it possible for students to test their theories against multiple what-if scenarios.

Nersessian (1999) states that: "in the constructive process of conceptual change, specifically, one important lesson we should take from the historical records is that models come first, then further abstraction takes place to create formal expression in laws and axioms of theories. . . The model is the mode of representation between the phenomena and expression in a language (including mathematics) and it is working with this intermediate form of representation that facilitates conceptual change" (p. 15).

Nersessian argues that this evidence "raises the modeling practices from their traditional status of ancillary, inessential aids to reasoning to the actual forms of reasoning through which concept formation and change take place" (p. 15). According to Nersessian (1999), "… forms of model-based reasoning are complex forms of reasoning that integrate various forms of information — propositions, models, and equations — into mental models" (p. 21).

Visual Modeling

One aspect that differentiates STELLA, and most other system dynamics software, from other types of modeling software are the use of graphical notation. This graphical representation system allows learners to conceptualize and test ideas about the mathematics of change without first mastering all the formalisms associated with calculus or advanced algebra. According to Nersessian, ". . . visual modeling appears to be a highly developed and effective form of human reasoning in a wide variety of circumstances. . . The thought-experimental process, by linking the conceptual and the experimental dimensions of human cognitive processing, demonstrates the undesirable real-world consequences of a representation, thereby compelling representational change. (p. 20-21). Observations of student performance and transcriptions of student responses on the student surveys in the redesigned class also indicate that the students have responded favorably to the use of graphical representations to support thinking within the modeling context.

Finally, another important reason for introducing students to the concept and practices of modeling is that models of different types are increasingly being used in policy decisions. Therefore, it is important for all students to understand both the benefits and limitations of models, and the various purposes they serve. For instance, system dynamics models do not claim to be able to predict exact times or quantities of specific variables, but are well suited to represent the effects of specific trends, and can provide an opportunity for testing theories about how things will differ under specific what-if scenarios.

This capacity provides as authentic a task as possible for students to perform in a classroom setting. This gives students an opportunity to assume the role of policy makers and manipulate various aspects of a model themselves to see what happens and to hypothesize and test their theories against a simulated version of reality.

Authentic Assessment Strategies

Jonassen and Reeves (1996) stress the importance of using multiple forms of assessment, and to provide tasks that will allow researchers to capture naturalistic data about how students actually learn in the context of using the specific technology as a cognitive tool. Results will be presented from this course, which has utilized multiple assessment strategies and rubrics, including paper and pencil exams, modeling assignments, interviews, and content analysis of debate performance to track students' progress.

Future Directions

Finally, plans for future semesters include implementing a continuous improvement approach to assessment, using student feedback compiled through multiple forms of data collection, to refine aspects of the course design and help students better learn concepts related to sustainable development, systems thinking, and dynamic modeling.

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