Progress in Education for Sustainable Development: Improving Learning Using System Dynamics[1]

Authors: Conor Meehan[2]; Therese Bennich[3]; David Collste[4]

1. The Challenge - Education for Sustainable Development with an Integrative Approach

Today's society is faced with a large number of inter-related challenges, including climate change, resource scarcity, biodiversity loss, inequality, poverty, and modern day psychological challenges (Steffen et al., 2015; Raworth, 2012). In the process of addressing these issues, education for sustainable development has become increasingly recognized and put at the core of development agendas on global, regional and national levels (EU, 2010; UN, 2015). Education for Sustainable Development aims to provide citizens with the knowledge, values, and skills necessary to shape a more sustainable future (EU, 2010). Teaching these complex and large-scale issues may, however, be challenging. A main obstacle in the field has been to create an in-depth understanding of the integrative nature of sustainability issues, which includes both natural and social sciences. In order to educate a new generation of sustainability leaders and citizens, we believe there is a need to create innovative models for learning that emphasize systems thinking and the use of participatory methods.

This paper presents an online module for education for sustainable development and systems thinking, developed in a collaboration between Loops Consulting and the Sustainability Laboratory (The Lab), a US-based nonprofit seeking to address urgent sustainability issues facing the planet. The module seeks to use the language of System Dynamics to teach The Lab's definition of sustainability and its related Five Core Principles of Sustainability, both of which are described in Box 1. System Dynamics was chosen as a medium for teaching The Lab's sustainability framework because both The Lab and Loops Consulting found it a useful language for explaining sustainability concepts such as carrying capacity, entropy, and circular economy. The module is open-source and can be used by anyone with access to the internet. The aim of the module is to provide a hands-on tool for teachers and students concerned with sustainability issues and to make a contribution to the discussion on new models for education for sustainable development. The module was designed with third level students in mind, however it may be useful for anyone from secondary school and upwards seeking to learn more about sustainability concepts and system dynamics.

---

[1] Note that this paper is based on a similar paper that will be published in a conference book.

[2] Loops Consulting, Dublin, Ireland. E: conor@loopsconsulting.com; M: +353861508271
[3] Department of Physical Geography, Stockholm University
[4] Stockholm Resilience Centre, Stockholm University

2. Theoretical background: Principles of Sustainability

To counteract what The Lab consider a growing ambiguity in the use of the term 'sustainable development' and 'sustainability', they offer a new and more rigorous definition of sustainability, focusing on the relationship between the population and the carrying capacity of its environment. As a means to achieve a state of sustainability, they also offer Five Core Principles of Sustainability, which are described in relation to five fundamental domains that are 'the primary dimensions of the population-environment interaction' (Ben-Eli, 2015). These domains are the Material Domain, the Economic Domain, the Domain of Life, the Social Domain and the Spiritual Domain. Each domain has a related principle, stated in a general way but intended to be operationalized in different contexts – applicable to for instance the various sectors of the economy, investment decisions, and individual decision-making. We see this framework as exploratory and complementary to other definitions of sustainability and sustainable development. The Sustainability Lab's approach to sustainable development is presented in Box 1.

Box 1: The Sustainability Lab's approach to Sustainable Development[5]

Sustainability is defined as: "a dynamic equilibrium in the process of interaction between a population and the carrying capacity of its environment such that the population develops to express its full potential without producing irreversible, adverse effects on the carrying capacity of the environment upon which it depends".

The Five Domains and Related Principles

The Material Domain
This domain is concerned with the principles regulating flows of materials and energy.

The First Principle
Contain entropy and ensure that the flow of resources, through and within the economy, is as nearly non-declining as is permitted by physical laws.

Examples of policy implications include ensuring maximum resource productivity and closed loops of energy and matter.

The Economic Domain
This domain provides a guiding framework for how to understand, create, and manage wealth.

The Second Principle
Adopt an appropriate accounting system to guide the economy, fully aligned with the planet's ecological processes and reflecting true, comprehensive biospheric pricing.

The policy and operational implications include employing a comprehensive concept of wealth, and incorporating externalities in cost and benefit accounts.

[5] For more information, see: http://www.sustainabilitylabs.org/approach/

The Domain of Life
This domain relates to the guidance of interactions of different forms of life in the biosphere.

The Third Principle
Ensure that the essential diversity of all forms of life in the biosphere is maintained.

For policy, this implies conservation of the existing gene pool and enhancing biodiversity.

The Social Domain
This domain provides the basis for social interactions.

The Fourth Principle
Maximize degrees of freedom and potential self-realization of all humans without any individual or group adversely affecting others.

Practical implications include establishing cooperation as a basis for governing planetary commons and addressing global issues.

The Spiritual Domain
This domain focuses on ethical and attitudinal orientations.

The Fifth Principle
This principle recognizes the link of mystery, wisdom, love, energy, and matter between the biosphere, the planet, and the solar system.

The principle highlights the need to embody a universal ethics, to guide human action towards a more compassionate and inclusive society.

The module presented in this paper makes use of the System Dynamics methodology. The module is not the only example of using system dynamics in an online context for education for sustainable development. Previous work in the field includes the simulation models found on the iseesystems website[6]. Similar to our work, these examples unravel SD simulation models in a step-by-step manner, and many of these models are dealing with issues related to sustainability (such as ecosystem management, for example). Additionally, there are several online role-playing games that use system dynamics models in order to simulate the impacts of certain decisions in different environments. The Fish Banks game, developed by Dennis Meadows and made available in an online format by MIT, is an example of this (Meadows et al, 2016). However, many of these games do not show the user the model that is being used to generate the outcome of their decisions. We believe this is a shortcoming in the sense that without understanding the model that produces the observed behaviour, students are less likely to internalise the messages found therein.

The Creative Learning Exchange has created a range of models and most recently apps that are designed to teach certain subjects, many of which are related to sustainable development. The target audience for this material is k-12 students in the

[6] http://xmile.iseesystems.com

United States. Additionally, System Dynamics has been used to teach sustainability topics in many areas of third level education. Universidade Nova de Lisboa in Portugal teach a module that uses System Dynamics as a medium for discussing many issues related to sustainable development. However, we are not currently aware of any education material that uses system dynamics for third level education for sustainable development and which is freely available online. The authors and The Lab hope that this module will fill this gap and allow third level students to develop their interest and skills in the use of modelling for education for sustainable development, no matter where they are located and what their financial situation is.

An integrated Module on Sustainable Development and Systems Thinking

In this section, we give a brief description of each of the eight exercises contained in the education module, with a more in-depth focus on Exercise 2. The module is freely available online, and can be used by anyone by using the following link: https://loopsconsulting.kumu.io/sustainability-definition-five-core-principles. The module was created using an online application known as Kumu.

Note that our purpose is to use System Dynamics to educate and present sustainability principles on a conceptual level. Thereby, none of our model's make use of real world data, as this would have unnecessarily increased the complexity of the material, and would likely not have assisted in increasing the understanding of the sustainability principles.

Exercise 1 in the module serves as a brief introduction to system dynamics, whereby the user learns about the kind of problems that system dynamics deals with, and why this particular methodology has been chosen as an aid to understanding some of the ideas found in The Lab's framework. The exercise also allows the users to familiarise themselves with the fundamental building blocks of system dynamics models (stocks and flows), and a simple bathtub model is built and simulated so that the user can see how the system dynamics simulation software works.

In Exercise 2, we focus on increasing understanding of The Lab's definition of sustainability, by demonstrating the meaning of the definition and its two clauses - namely, that the population is allowed to reach its full potential, and that it does not irreversibly harm the carrying capacity of its environment in doing so. These conditions are demonstrated through the construction and simulation of a model of an imagined population stranded on a resource-constrained island. This island serves as an analogy to Earth.

Through building the model, the user is introduced to concepts such as carrying capacity, resource sufficiency (which is taken as a simple proxy for human well being), and dynamic equilibriums. At the same time, the user is introduced to new system dynamics concepts not found in Exercise 1, such as reinforcing and balancing feedback loops, and the use of equations and look-up functions to represent relationships between variables in the model.

The user is brought through a step-by-step development of the model, and we simulate the model with different structures - first with no carrying capacity, then with a static carrying capacity (represented in a simplified manner by food available), then with a dynamic but self-reproducing carrying capacity (represented by wild food) and finally with a dynamic but human-controlled carrying capacity (represented by farmed food). For each simulation, the user is asked to use a pen and paper to sketch their own guess of how the population will develop over time. This is done for every simulation in the module, with the hope that it will develop the user's ability to infer dynamic behaviour arising from the structure.

An image of the model used for this exercise (taken from the module) is seen below. The user can click on any of the variables in the model map to see a description of that variable's value, equation, and/or meaning.

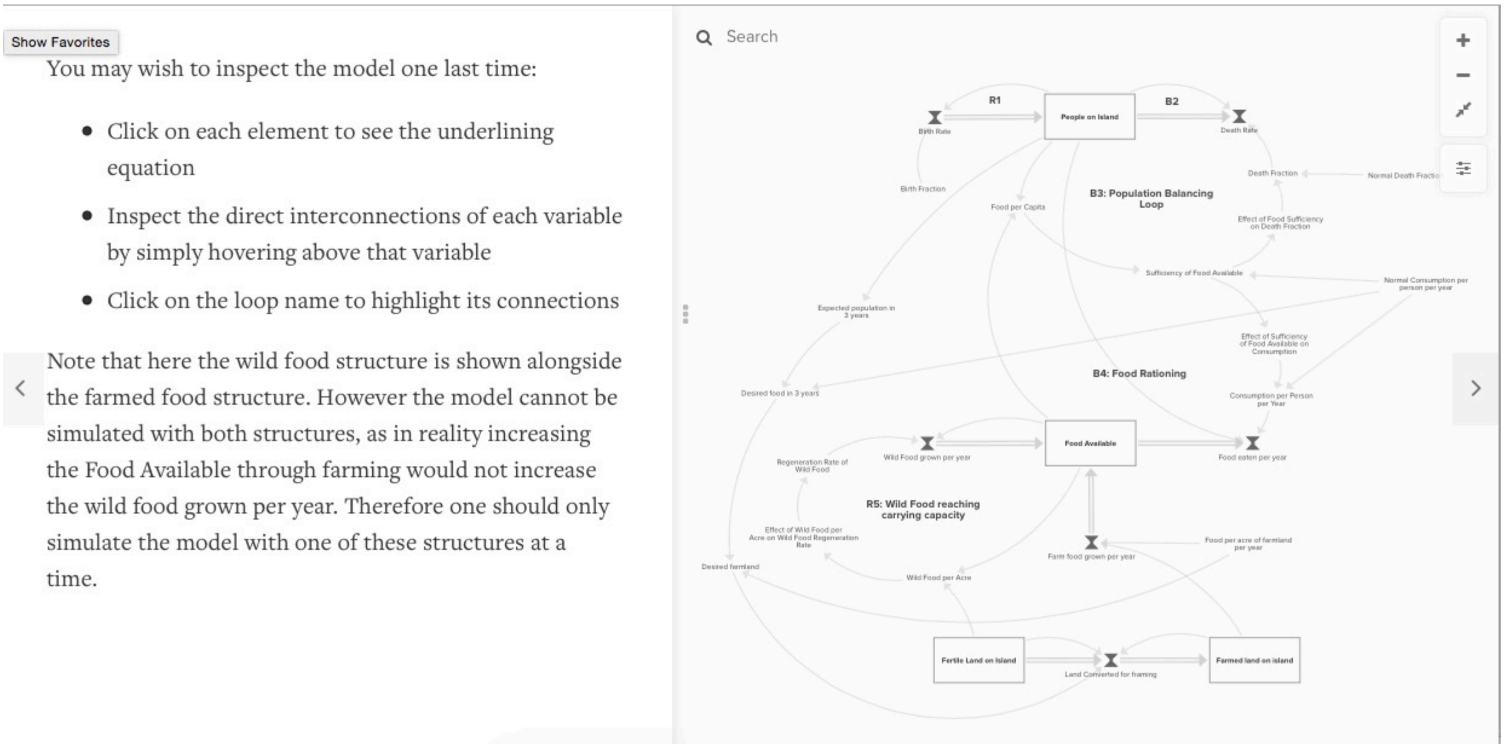

Figure 1: a screenshot of one of the pages from Exercise 2, which shows the model used in that exercise.

An image of the simulation result for the self-reproducing carrying capacity (i.e. wild food) structure of the model can also be seen below. These simulations were produced using online published models made with the Stella Architect software. These models were exact replicas of the models shown in the module (i.e. shown in the Kumu software):

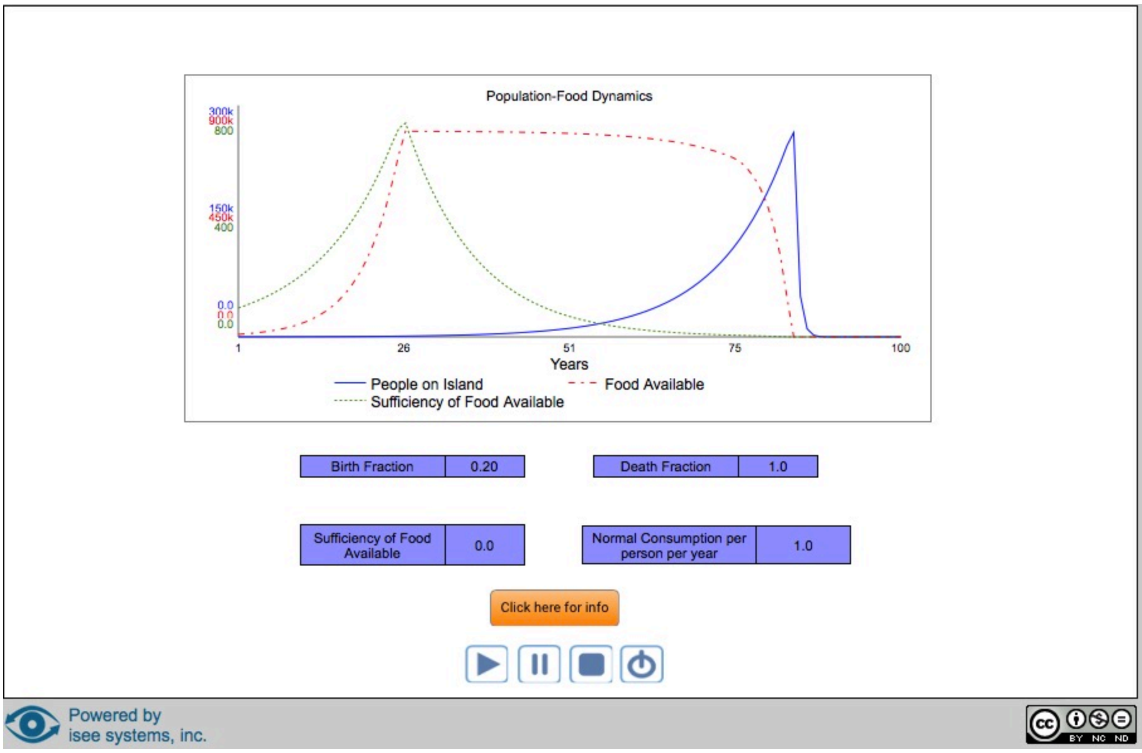

Figure 2: a screenshot of one of the simulation results from Exercise 2

The underlying causes for the simulated behavior are discussed in detail, in terms of the changing dominance of different feedback loops over time. Limitations of the model are then noted and some are justified, such as the use of arbitrary numbers and the lack of representation of any of the effects of pollution.

In the next five exercises, Exercises 3A, 3B, 3C, 3D, and 3E, we deal with the topic of The Lab's Five Core Principles of Sustainability. The main aim of each of these exercises is to increase understanding of each of the principles. This means both increasing understanding of the logic behind each principle (i.e. why does The Lab identify this as a principle of sustainability?), as well as increasing understanding of the operational and policy implications of each principle (i.e. what do applications of this principle look like?). The ultimate aim, however, is not just an intellectual understanding of the principles. Indeed, the ultimate goal of the principles themselves is not the prescription of a set of rules to be followed, but rather to provide a holistic and rigorous framework in which people can ground their understanding of some of the most important aspects surrounding the concept of sustainability, and maintain an awareness of its interdisciplinary nature.

Exercise 3A, which deals with the principle relating to the material domain, demonstrates the laws of conservation of energy and mass, and the law of increasing entropy (also known as the first and second laws of thermodynamics) and discusses their policy implications. A small system dynamics model is used to explain concepts in this domain, although the system dynamics methodology was not relied upon to the same extent as in the other exercises.

Exercise 3B deals with the principle relating to the economic domain. The main goal of this exercise is to show how alternative ways of accounting for wealth creation and incentivising the creation of wealth can lead to a more sustainable relationship between a population and its environment. In terms of accounting for wealth creation, we use a system dynamics model to demonstrate how GDP can be very misleading in how it accounts for the creation of wealth, even in purely materialistic terms. And in terms of incentivising new ways of creating wealth, we discuss (without a model) how imposing a cost on natural resource depletion and environmental pollution can incentivise the use of renewable energies as well as the establishment of the circular economy and the products-as-a-service economy. Finally, we discuss the importance of incorporating a measure of wellbeing in economic calculations, and provide some examples of recent efforts to achieve this.

Exercise 3C deals with the principle relating to the domain of life. We begin by discussing the importance of nature and biodiversity for human wellbeing, in terms of direct and indirect ecosystem services that it provides, as well as its aesthetic or spiritual value. We then move on to show a less obvious benefit of biodiversity in particular - ecosystem resilience. To demonstrate this we take an example from the coral reefs in Jamaica, where overfishing in the 1960's eventually contributed to an algal bloom that occurred in the 1980's. We use a system dynamics model to demonstrate how there can be a cause and effect relationship between these two events that happened two decades apart. The overall aim of this model is to demonstrate the way in which biodiversity increases ecosystem resilience, by modelling the interdependence between organisms in a complex ecosystem.

The exercise also discusses the economic implications of overfishing, demonstrating the fact that sustainable fishing methods may have produced smaller catches in the short term, but allowed for much larger catches in the long term. This in turn results in greater health for coral reefs and other ecosystems, as well as greater economic well being for the fishing industry and its customers over the long run. This point is driven home through a simulation of the model that uses a stock to track the 'Total Fish Caught' over the whole simulation period.

Exercise 3D deals with the principle relating to the social domain. This exercise discusses some of the theories that drives the logic of the principle, such as human fallibility, which implies that no one group or individual has the right to impose their beliefs on others. It also introduces the user to the use and meaning of Causal Loop Diagrams (CLDs). We then construct a CLD of the social dynamics of two individuals or groups that each seek to reach their own self-determined goal. The diagram serves to clarify the dynamics that can reinforce the desired or undesired nature of social relationships (whether those be between individuals or groups).

Exercise 3E discusses the principle relating to the spiritual domain. The goal is for the user to understand the principle as a perspective proposed by The Lab which could inspire people towards wanting to achieve a state of sustainability on the planet. The perspective also acts as a basis upon which a universal code of ethics could be formed.

In the final exercise, Exercise 4, we discuss The Lab's idea of how achieving sustainability requires an approach that addresses each domain simultaneously, and that each domain affects the others and is affected by each in return. In other words, we discuss how the achievement of sustainability requires a systemic approach, whereby emphasis on one domain without emphasis on the other is unlikely to achieve effective and long-lasting results.

5. Concluding Remarks

We have designed an open access online education module to allow students to utilise the power of System Dynamics to better understand the definition of sustainability and its related Five Core principles, as described by a non-profit known as The Sustainability Laboratory. We believe that the module contributes to education for sustainable development in several ways.

Firstly, The Lab's content provides a holistic framework in which one first understands a technical and rigorous definition of what sustainability means, and then also understands the interdisciplinary approach needed to achieve this system state, relating to its physical, economic, ecological, social, and spiritual challenges.

Secondly, the use of System Dynamics provides a new approach to The Lab's framework, and one which we found to be valuable. In particular, we found System Dynamics useful for making theories explicit through the use of CLDs and simulation models, which we believe are less ambiguous than verbal or written descriptions of such theories. For example, in Exercise 2 the definition of sustainability is made more explicit by first building a model which uses real world variables to describe each of the abstract concepts found in The Lab's definition (e.g. carrying capacity was represented by the stock of food available on the island). The characteristics of a sustainable population are then made explicit through several simulations of the model, and we discuss whether or not the population exhibits sustainability in each of these simulations, and the reasons why.

The use of the Kumu software proved to be extremely helpful in allowing us to have large bodies of text broken up by pages with step-by-step unravelling of SD models, all whilst maintaining a visually appealing aspect to the module. Kumu also allowed us to keep the model's equations "in the background", which allowed us to keep the focus on the meaning of the model, whilst allowing the more technically curious students to delve further into how the model produces its results, and the assumptions built into it (this can be done by clicking on the variable names in the model, which brings up a text box in which one sees the variable's equation and some text describing the logic and assumptions behind this equation). We hope that the module will be an engaging and enlightening introduction to Systems Dynamics for those not already familiar with it.

Potential future developments include making the module more interactive, to allow students to gain further modelling skills and the ability to create System Dynamics models on their own. In order to let the users more fully develop skills in system dynamics, the module may be complemented with other online tools such as games or exercises that assist the user in learning how to build a model from scratch. We are also eager to facilitate web based or real life workshops with the module as a starting point to further assist the learning.

References:

Axelrod, R. (2003), Advancing the Art of Simulation in the Social Sciences. *Japanese Journal for Management Information Systems* 12(3): 1–19.

Ben-Eli, M. (2015), *Sustainability: Definition and Five Core Principles.*

EU, (2010), *Council conclusions on education for sustainable development.*

Forrester, J. W., (1969) *Urban Dynamics,* Massachusetts: Pegasus Communications.

Meadows, D. (2008), *Thinking in Systems: A Primer,* Chelsea Green.

Meadows, D., Sterman, J., King, A. (2016), *Fishbanks: A Renewable Resource Management Simulation*

Meadows, D., Meadows,D., Randers, J. and William W. Behrens III, (1972), *The Limits to Growth: A Report for THE CLUB OF ROME'S Project on the Predicament of Mankind*, New York: Universe Books.

Meadows, D., Meadows,D. and Randers, J. (2004), *Limits to Growth: The 30-Year Update,* Chelsea Green.

Raworth, K. (2012), *A safe and just space for humanity: can we live within the doughnut*, Oxfam Policy Pract. Clim. Change Resil. 8, 1–26.

Steffen, W., Richardson, K., Rockström, J., Cornell, S.E., Fetzer, I., Bennett, E.M., Biggs, R., Carpenter, S.R., Vries, W. de, Wit, C.A. de, Folke, C., Gerten, D., Heinke, J., Mace, G.M., Persson, L.M., Ramanathan, V., Reyers, B., Sörlin, S. (2015), *Planetary boundaries: Guiding human development on a changing planet*. Science 347.

UN, (2015), *Transforming our world: the 2030 Agenda for Sustainable Development.*