Fierce Planet: Sustainability Learning through Gaming and Simulation

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Fierce Planet is an experimental agent-based modelling (ABM) platform for developing and testing urban sustainability scenarios. Developed as part of the Sustainable Urban Precincts Program initiative to incorporate sustainability concepts into learning and teaching across the curriculum at RMIT University, the platform is designed to facilitate teaching of sustainability concepts, theories and problems in tertiary courses. This discussion paper introduces agent-based models and their application to the social and environmental sciences. We then outline how we develop a series of such models to represent historical and present understandings of sustainability commonly taught in tertiary courses. In particular we consider the pedagogical advantages of ABMs as a graphical representation of the progressive complexity of sustainability models – enabling students to visualise the movement from simple Malthusian models containing two to four variables, through to the more complex “Limits to Growth” model containing eight variables, and beyond. This increase in modelling complexity is significant, not only in understanding contemporary sustainability challenges - both popular and academic literatures on climate change feature considerable debate about the construction and interpretation of mathematical models for example - but also in thinking through associated questions about the increasing role of modelling and simulation in rhetoric and argument. We discuss how ABMs represent a comparatively recent approach to treat this problem through graphical animation rather than textual or mathematical representation, and outline a pilot research design to evaluate how this approach might elucidate otherwise complex sustainability theoretical literature in a classroom context.

Keywords: Agent Based Modelling (ABM), theories of sustainability, complexity, simulation, tertiary education, pedagogy

Introduction

This paper explores the potential of agent-based modelling (ABM) platforms to support the teaching of undergraduate sustainability courses. ABMs refer to a set of computational techniques for modelling complex systems, including social systems, through the use of 'agents' - software objects that mimic properties and behaviours of real-world actors. In models used in the social sciences, these actors are usually humans, or ‘higher order’ social structures such as institutions. ABMs have been developed to model situations such as traffic flows, voting patterns and consumer choice, where complex group behaviour appears to emerge from the simple programmed interactions between individual agents.
In the context of tertiary pedagogy, ABMs can offer students a means of visualising, and experimenting in a hands-on fashion, with complex social and environmental interactions conventionally taught through text, mathematical modelling, or passive media. However ABMs introduce their own challenges in a teaching context. To develop models requires domain and programming expertise, and such models are often used to support a particular disciplinary orientation. Moreover they can be difficult to embed in online teaching environments, as their supporting frameworks require software to be installed on student or laboratory machines.

In this paper we describe a project that seeks to overcome some of these limitations, with particular reference to the teaching of an introductory course on the historical development of interpretations of the concept of sustainability. We propose that a series of “familial” ABM models can be used to characterise, in very broad outline, a number of critical moments in the development of sustainability concepts. For example, Malthus’ treatment of problems of demography; the Club of Rome’s construction of mathematical models to explain resource consumption; the seemingly infinite expansion of agricultural yields heralded by the Green Revolution; and the Triple Bottom Line model of sustainability (Elkington, 1999) can be presented, we argue, through student engagement with a series of ABMs that enable students to explore both variation and commonality between these different moments. We illustrate this approach by outlining an exemplary undergraduate syllabus that presents the refinement of sustainability concepts, models and arguments in the form of a “history of ideas”. In this exemplar course, core weekly readings, exercises and discussion would be supplemented by students experimenting with a series of corresponding ABMs. The weekly readings comprise excerpts from relevant canonical texts which have been selected to clearly and concisely present key claims and assumptions of each approach to sustainability. The supplemental simulation activities are designed to provide pedagogical support in helping students to understand, and to interrogate critically, the assumptions, parameters and outcomes that underpin particular understandings of sustainability. Our project is currently developing both the exemplary “proto-syllabus”, and the particular ABMs to support it, in preparation for piloting in real-world classroom environments in later stages.

Below we discuss what we see as the benefits and limitations of both the model syllabus and its supporting ABMs. We argue that the exemplary course demonstrates how ABMs can add significant pedagogical value by helping students visualise and understand, in a more hands-on and concrete way, the parameters and implications of different conceptions of sustainability. We further argue the illustrative value of ABMs is more clear-cut in relation to the historical texts discussed here, where computational techniques are either unavailable or, as with the celebrated case of the Limits to Growth and its computational model World3, the subject of highly contested methodological and political discussion. As a recent review literature by Bond, Morrison-Saunders and Pope (2012) suggests, since the arrival of the Triple Bottom Line in the 1990s approaches, techniques, methods and models for conceptualising and assessing sustainability with different temporal and spatial scales and scopes have grown exponentially. Many of these approaches, such as System Energy Assessment (Henshaw, King and Zarnikau, 2009), Integrated Sustainability Assessment (Weaver and Rotmans, 2006) and various “footprint” calculators (Galli et al, 2012), are both less settled in terms of scientific paradigm and consensus, and more complex in terms of method and calculation. The trade-off in terms of time and cost of model development to pedagogical benefit becomes accordingly more difficult to justify. The open source and extensible simulation framework we have developed does however make feasible modular extensions in line with theoretical orientations and learning objectives of particular tertiary courses.

**Teaching sustainability to undergraduates**

Sustainability and sustainable development are increasingly important components of many tertiary courses in the social and physical sciences (Tilbury 2011; Eilks & Rauch 2012; Trowler, Hopkinson & Comerford Boyes 2013; Lozano, Lozano, Mulder, Huisingh, & Waas 2013; Scott 2014). RMIT University in particular considers the fostering of sustainability to be one of its foundational values, informing the actions and future directions of the institution. RMIT has therefore encouraged the teaching of sustainability across the curriculum, rather than within the academic ‘silos’ of specialist subjects. At the same time, the university has also encouraged specialist sustainability courses to explore the concept in greater depth.

One of the challenges in teaching sustainability to undergraduates is the highly contested nature of the concept. Courses that begin with a static definition of sustainability, for example that put forward in the Brundtland Report and the Triple Bottom Line (United Nations General Assembly, 1987; Elkington, 1999), can obscure its important intellectual history, and leave students ill-equipped to understand and engage with its recent fragmentation and adaptation into related theoretical vocabularies of liveability, quality of life, and, in particular, resilience. While this intellectual history can be communicated through conventional pedagogical strategies - lectures, readings, and tutorial discussions - undergraduate students can still struggle with both the abstraction and the complexity of epistemological orientations, writing styles, and modelling techniques required to make sense of the development of sustainability concepts.

One way to engage with this intellectual history is through the presentation of a number of key historical moments in the conceptual trajectory of sustainability. This narrativised or historised approach seeks to illustrate the theoretical development of sustainability concepts through a family of models that share key characteristics and which correspond to a particular understanding of sustainability. One key assumption of such a narrativised approach is that particular theoretical developments reflect the preoccupations of their contemporary contexts. For example scientific and technological developments and the broader social processes of rapid industrialisation and urbanisation have led to concerns over unchecked development and growth exceeding the limits of the earth’s ‘carrying capacity’ (Meadows et al, 1972).

We argue that such a narrative approach to the historical development of ‘sustainability’ must address the changing relationship between ‘progress’ and its relationship to ‘growth’. Progress can be understood simply as the continual movement of human societies, through the efforts of their participants, towards improvements in the physical, emotional and moral and/or spiritual quality of life. This teleological concept has been enormously influential within the Western cultural tradition in particular (Sklair, 1970; 1971; Pinker, 2011; Wessels, 2006; Greer 2008; 2013). Most problematically, scientific or technological progress and moral progress have often been seen as interchangeable - a point explicit in Comtean Positivism ¹, but often tacitly expressed in later periods (Sklair, 1970). However since the world wars, progress has come to be evaluated more sceptically, and the assumption that moral progress would align with technological and scientific progress has been called into question (Elias, 2000; Horkheimer & Adorno, 2002; Sklair, 1970). Further contestation has also arisen over the need for limits to growth and the challenge this implies to this idea of endless material progress. This tension informs the narrative approach of our exemplar course.

In pedagogical terms we propose that these historical and conceptual transitions can be explained by presenting specific agent-based models of sustainability alongside the historical texts which best outline the corresponding theory. These models are designed not only to provide a way of visualising how specific understandings of sustainability might operate in their own terms but also to show how models relate to previous or subsequent approaches within the development trajectory of sustainability theory. Though less common in the social than the natural sciences, computational simulations of various kinds have been widely used in educational settings. Agent-based models are an increasingly popular method of building and running simulations, since they can combine pre-scripted behaviour with randomised elements to illustrate complex patterns of causal influence. NetLogo, a popular agent-based modelling environment, has been used to support class-based experimentation in “virtual laboratories”, with pedagogical applications in urban planning (Hjorth & Wilensky 2014), ecology (Gkiolmas et al 2014), chemistry (Kottonau 2012; Levy & Wilensky 2009) and scientific method (Brady et al, 2014). In the context of sustainability, students can experiment in such virtual laboratories by adjusting parameters and settings to show how combinations of resource consumption, weather patterns, agricultural yields and individual agent interactions can produce radically different estimates and outcomes. Gourmelon et al (2011; 2013), for example, demonstrate the use of agent-based models in a role-playing game designed to teach French high-school students about sustainable development. In other learning contexts, researchers have used digital games, participatory simulation or companion modelling approaches to include, inform and learn from local community groups about the sustainability implications and consequences of resource management and land-use policies

¹ For Comte (1798–1857) the social and moral progress of society follows the same inescapable teleological trajectory as scientific and technological development (moral progress through scientific progress) (Sklair, 1968).
These applications suggest some of advantages of incorporating highly visual and interactive ABMs into classroom materials to aid in student learning. At a tertiary level, we argue ABMs have three particular benefits: they can expand student understanding of sustainability theories by bringing an experimental and exploratory element to the teaching of otherwise abstract definitions and theoretical concepts; they can encourage participation across disciplinary groups by enabling and rewarding the application of insights from multiple disciplines; and they can make durable interpretations of sustainability generated in previous courses, through preserving a record of specific settings and calibrations that can add greater depth to subsequent courses.

A proposed (exemplary) undergraduate sustainability course

In this section we present an exemplary undergraduate course based upon the use of ‘canonical’ texts which are seen to most clearly outline selected theories of sustainability and illustrate the course’s overarching ‘narrative’ of the changing ideas and contestations of ‘sustainability’, ‘sustainable development’ and ‘limits to growth’ through time (Carew & Mitchell 2008; Pappas 2012). Our hypothetical students would read these extracts and then identify their key assumptions and claims; these would then inform the parameters of the corresponding simulation. Students would then run the simulations, individually or in groups, adjusting parameters and observing the varying outcomes. The pedagogical approach therefore involves exploring and manipulating the parameters of the various models to better understand the many outcomes and implications of different theories of sustainability or limits to growth.

Underpinning this course is an understanding of theories of sustainability and ‘limits to growth’ as developing through time. However the progression of ideas presented here is neither exclusive, exhaustive or even necessarily historically linear. For example the ‘Green Revolution’ and Simon’s ideas about infinite growth occur at around the same time (the mid 70’s) as The Limits to Growth book and were in part written to counter the claims of the Club of Rome. To a large extent they are antagonistic contemporaries. Nevertheless, the development of theories of sustainability can be organised into a general progression for pedagogical purposes, and four distinct models of sustainable development have been chosen to demonstrate and explore this idea. These are:

1. Malthusian growth
2. Limits to Growth
3. The Green Revolution
4. The Triple-bottom Line or Sustainable Development

All ABMs are developed in an experimental web-based framework called Fierce Planet (Magee 2012; 2014), which allows the models to be easily integrated into online courseware systems such as Blackboard.

What now follows is a brief exploration of each model of sustainable development, including the canonical text and corresponding Fierce Planet simulation, to help clarify the approach of the exemplar course.

Malthus

Thomas Malthus’ An Essay on the Principle of Population represents the first real attempt to mathematically model a ‘limits to growth’ argument. Given that any determinist warning about the interactions between the food supply and population is today labelled Malthusian (or neo-Malthusian) his famous essay is taken to be the canonical text for such worldviews. The version used is the original print of 1798 (accessed through the project Gutenberg website) and the complete chapter 1 would be the prescribed reading for the first component of the exemplar course.
Malthus is deeply pessimistic about the future of any human society and argues against the notion of teleological progress, criticising the very concept of the eventual moral and social ‘perfectibility of man’. His critique is based upon two interconnected trends: unchecked population growth which can only be definitively restrained by the limits of food (resource) availability. At some point in time the population must inevitably overshoot the carrying capacity of the food supply and a population ‘crash’ will result. The population will fall back to a level which can be sustained by the food supply and the whole dynamic will repeat.

Course participants must read the excerpt of Malthus’s work and identify (whether individually or in pairs/groups) the two main parameters of his theory: population and food (or energy/resources). A third implicit parameter - public health - could be considered a consequence of the former two, as it must inevitably fall as the food supply is squeezed by population growth and famine approaches. The Fierce Planet simulation offers students the opportunity to manipulate these parameters, and to then run the simulation a number of times.

Finally Malthus suggests that moral (and thus reproductive) rectitude (as well as a self-interested awareness of the costs of raising children) could lead to a reduction in the birthrate of the contemporary lower socioeconomic classes. He sees this as only slowing the inevitable day of demographic reckoning. This further parameter can also be modelled in Fierce Planet by adjusting the birthrate of the simulation agents so that the population grows more slowly over time.

**Agent Based Simulation**

All of the models shown here use satellite data to model the underlying terrain. We have selected data representing Melbourne and Port Phillip Bay. The terrain is segmented into a series of square patches or cells, an approach common to ABMs, and here representing allotments of food resources. The abundance of food is indicated by the shading of the patch: the lighter the shade, the greater the available food. Patches are randomly allocated a starting allotment; this random allocation appears as a quilt-like effect across the landscape. The agents, indicated by the green stick figures, begin the simulation in a clustered concentration. Their movement in this model is randomised, though once agents have chosen an initial random direction, that direction will only be perturbed in small increments. As they move from patch to patch, the agents grow hungry, and they consume the resources of the patch they currently occupy. The screenshot captures the simulation just after it has begun. The agents have started to spread, and accordingly the patches they occupy are depleted of food resources. As the simulation continues, agents continue to exercise, consume, reproduce and die. When patches are freed of agents, they replenish back to their starting conditions. Over time, the model shows the agent population expanding, over-consuming, and dying out. Different combinations of patch resource yields and recovery rates, exercise costs and reproduction rates generate alternative outcomes: boom-and-bust cycles (where the population, reaching a low point, manages to recover); a stable equilibrium; and endless growth. By adjusting these parameters, students can experiment with Malthusian predictions as well as other possible scenarios.
The Club of Rome and *The Limits to Growth*

While economists such as Soddy (1912, 1922, 1926) had considered energy as a limiting factor on economic growth, theoretical interest in the Malthusian concept of a limit to growth gained particular prominence in the 1960’s and 1970’s alongside the rise of ‘movement’ environmentalism and the effects of the OPEC oil embargo. At this time a range of economists and social theorists re-examined classic Malthusian concerns with the economic and social constraints posed by finite resources (Ehrlich & Ehrlich, 1968; Georgescu-Roegen, 1970; 1977; Gowdy & Mesner, 1998; Daly, 1974). At the same time environmental awareness focussed attention on the effects of uncontrolled growth (including pollution and population pressures) as a further threat to the sustainability of human societies. While these remain contemporary concerns (Proops, 1983; Brown et al, 2011; Foster, 2011; Odum 1971; Raine et al, 2006; Tverberg, 2012) perhaps the most famous treatment was the modelling work of The Club of Rome’s *The Limits to Growth* (Meadows et al, 1972). Pages 121-125 of 1972 edition of this text are therefore used as the classroom reading exemplifying theories concerned with the effects of both environmental degradation and thermodynamics and entropy on sustainability.

The importance of *The Limits to Growth* lies in its increasingly sophisticated attempts to model, through computer simulation, the effects of resource and environmental limits on both economic and population growth, in order to predict and simulate the trajectory of such limits on complex world and social systems. Compared with the simple Malthusian model of two variables, the Limits to Growth model proposes eight:

1. population (total number of persons)
2. industrial output per capita (dollar equivalent per person per year)
3. food per capita (kilogram-grain equivalent per person per year)
4. pollution (multiple of 1970 level)
5. nonrenewable resources (fraction of 1900 reserves remaining)
6. crude birth rate (births per 1000 persons per year)
7. crude death rate (deaths per 1000 persons per year)
8. services per capita (dollar equivalent per person per year)

Their baseline simulation assumed a static situation in terms of human systems of economic activity; capital accumulation and social values.
Although more sophisticated, the simulation results in the broadly Malthusian model of exuberant growth followed by collapse.

Since the theoretical parameters of the model are so clearly stated in the excerpt, classroom discussion can draw out the students’ awareness that this text (unlike the theory of Malthus) is based upon the results of a computer simulation. The Fierce Planet simulation is therefore attempting to recreate the original modelling which underlaid the theoretical exposition contained in the excerpt.

Agent Based Model

Like the Malthusian model, the *Limits to Growth* model uses the same idea of patches; rather than food resources directly, here the patches represent non-renewable resources. Since *Limits to Growth* takes the depletion of non-renewable resources as the main causal driver of population collapse, we set the default rate of recovery to zero in this model. The starting population and birth rates are additional inputs, while death rates, industrial output, food, services and pollution are all outputs. In *Figure 2* below, again we track population in the graph with the blue line; food production is represented in red; and nonrenewable resources in green.
The Green Revolution

The next theoretical approach discussed in the course is labelled the Green Revolution and provides a trenchant critique of Malthusian and neo-Malthusian limits to growth. Its critique is based upon a theorisation of the impacts of new techniques, including the introduction of new high yield crop varieties, better and more extensive use of irrigation and synthetic pesticides and herbicides and developments in agricultural management. These advances reduced the Malthusian spectre of hunger or famine across many areas of the developing world (Jain, 2010; Hazell, 2009) and thus challenged ‘limits to growth’ arguments.

The course considers Simon’s *The Ultimate Resource* (1981), written as a direct critical response to the *Limits to Growth*, as the representative text for such approaches. The course will use two excerpts from the original version of this work: chapter 4 (pages 54-69) and the start of chapter 14 (pages 196-203).

Simon’s overall argument is that contemporary positive developments - falling energy costs and rising human development indicators and technological advancements - will continue indefinitely and uninterruptedly. He considers all resources as infinitely substitutable, and sees advances in technology as allowing for both infinite resource substitution and the ever-increasing efficiency of energy use which makes any limits to growth meaningless. Simon reverses the Malthusian paradigm by arguing that population growth will actually lead to fewer famines or resource shortages and less environmental damage, as increasing population growth means more future technological advances which will ameliorate any such difficulties.

Classroom discussion needs to identify the philosophical basis of Simon's argument and where it differs from the Malthusian approaches. For Simon human ingenuity (the ‘infinite resource’ of his title), exemplified by the advances of the Green Revolution, reaffirms the narrative of ‘progress’. In such a cornucopian view any ‘limits to growth’ are simply non-existent. Translating this argument into the *Fierce Planet* platform means reversing the Malthusian causal relationship between population growth and resource degradation. For Simon population growth (and the resultant increase in the stock of human ingenuity) reduces the rate of resource depletion and environmental damage while the stock of available resources increases.

Agent Based Model

The Green Revolution builds upon the Limits to Growth model, but assumes that resources are renewable or substitutable (whether through pricing mechanisms, policy legislation, technological change, or patterns of consumption), as well as a gradually higher rate of production, through technological innovation. We introduce a further parameter representing an annual rate of increased food production relative to the store of non-renewables to reflect Simon’s view that human ingenuity will outperform limits to resources and growth.

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The fourth and final theoretical concept of sustainability, connecting the Triple Bottom Line (TBL) and Sustainable Development (SD) approaches, argues that the interconnected parameters of economy, society and environment must be brought into balance so that their complex interplay can be sustained through time. This approach has become so widely accepted as to be almost axiomatic amongst business, environmental, NGO and government stakeholders. The term Triple Bottom Line was largely popularised by Elkington’s 1999 book Cannibals with Forks and his call to balance the business imperative of economic growth against its environmental and social costs is not substantively different from the concept of Sustainable Development (SD) (Vanclay, 2004) popularised by the Brundtland Report (United Nations General Assembly, 1987)

This understanding of sustainability accepts neither the Malthusian endpoint of systemic collapse nor the endless growth and technological triumphalism of Simon’s cornucopian worldview. It acknowledges environmental and social limits to growth (such as resource depletion, pollution and social inequality), while arguing these limits are neither absolute or inescapable. Instead sustainable development is achieved through a ‘balancing act’ between these three interconnected parameters (or ‘bottom lines’) to maintain of some sort of stable and ongoing equilibrium.

Given the broad range of conceptual understandings of the concept of TBL / SD, and the wide range of normative metrics for measuring the three ‘bottom lines’ the choice of a ‘canonical’ text for this approach to sustainability is as difficult as the challenge of modelling it. While Chapter 1 Part 4 of Cannibals with Forks (Elkington, 1999) and Chapter 2, Part A of the Brundtland Report (United Nations General Assembly, 1987) provide conceptual overviews of the TBL and SD respectively they do not provide clear normative parameters for modelling these approaches in an ABM simulation. Given these issues this approach to sustainability is most usefully encapsulated in a modelling sense by either the tripartite Venn diagram or the ‘three legged stool’.

Available at: http://www.acts.asn.au/conference-proceedings/
What these graphic representations offer, however imprecisely, is the overall understanding that sustainability depends upon the achievement of a provisional and endlessly negotiated equilibrium amongst these three competing but complementary components. Classroom activities will need to help students see the theoretical (and indeed philosophical) differences between this understanding of sustainability and both the Malthusian and cornucopian theories.

Agent Based Model

The *Triple Bottom Line* model modifies the output variables of the *Limits to Growth / Green Revolution* models, shown in the graph in *Figure 4* below. It takes population as a basic proxy for "social" or "people" (shown by the red line below); production levels are taken as proxies for "economic" (shown in blue); and a further notional idea of degradation is derived from the accumulated impact of agents in the "environment" (shown in green). Less relevant here are the specific trends; rather the fact that different trend lines can be shown to go in different directions based on specified parameter values.

**Figure 4: The Triple Bottom Line (Blue - Economy; Green - Environment; Red - Social)**

Conclusions

Incorporating ABMs directly into a hypothetical sustainability syllabus, our approach enables otherwise abstract and large-scale ideas to become amenable to more accessible visual representation and
experimental manipulation through a problem-based learning strategy. In future, these web-based simulations could be extended and adapted as part of a suite of modules that can be deployed in a wide variety of courses, across different disciplines, to enable the incorporation of sustainability concepts throughout the curriculum, rather than being restricted to a specialist subject. Equally, such modules could incorporate related social and ecological concepts and indicators of resilience, adaptation, mitigation, vulnerability, and risk. While our approach has begun with an exemplar specialist subject, the next stages involve both testing the exemplar as a standalone subject, and then thinking through possibilities for modularising elements of the course for possible use in exploring sustainability implications in non-specialist subjects.

We recognise limits in this pedagogical approach. The most obvious is the large epistemological assumption involved in treating the historical development of the concepts of ‘sustainability’ or ‘limits to growth’ as a coherent narrative in which such ideas become progressively more complex as both conceptual understanding and modelling technologies improve - that is, the assumption that these theoretical understandings have a shared lineage which can be traced through their development in time. Such an approach presupposes that all significant sustainability theories can be meaningfully represented through the use of ABM simulations and that these representations will demonstrate their shared historical and theoretical heritage. The rapid proliferation of interpretations of sustainability, including those incorporating non-European conceptualisations (e.g. Plessis, 2001, Schwartz, 2005), suggest this coherence can increasingly be interrogated. Such limitations require a degree of calibrated scepticism on behalf of the teacher - where it is not already forthcoming from students.

Indeed a further use of ABMs in a virtual laboratory setting, where assumptions and parameters can be inspected and unpacked, is to develop and extend a critical literacy in the use of technologically-aided modelling, analysis and visual representation. Such skills will be increasingly in demand, as complex models, “Big Data” and sophisticated visualisations dominate popular and academic literatures in the natural and social sciences. This is especially the case for sustainability science and related fields such as macro-economics, international development and climatology, where global effects are partially produced through the complex interactions and behaviours of local agents and their environments.

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