# EXPLORING A COMPLEXITY MODULE FOR THE IB DIPLOMA PROGRAMME

ROLANDKUPERS CONSULT
ELLEN MACARTHUR FOUNDATION
UWC

## INTRODUCTION

In the closing days of the 20th century, Stephen Hawking expressed his conviction that the next century would be the century of complexity. The study of complex systems has become an important part of the curriculum of universities around the world. As described in an International School magazine article1, the good news for IB teachers is that IB programmes already contain a wealth of opportunities to explore complexity and complex causality.

With strong encouragement, support and guidance from the International Baccalaureate Organisation, and the Ellen MacArthur Foundation, we developed a complexity module for the diploma programme. The Mahindra United World College (MUWCI) in Pune, enthusiastically volunteered to be the trial site where the course was delivered and further evolved through several iterations in 2016 and 2017. The MUWCI staff and students made invaluable contributions to the content.

The resulting curriculum was designed to be delivered through seven modules of two-hours each, in conjunction with the IB Diploma Programme. Complex systems connect at many levels with the existing teaching material and further suggestions are included on how to make those connections explicit. The experience at MUWCI showed that students respond enthusiastically and teachers readily identify ways to connect to the core curriculum.

Much remains to be learned and discovered about teaching complexity in schools, but we sincerely hope that this material will encourage more experiments and learning. Students will be better equipped to deal with the interconnected challenges of the 21st century.

**AUTHORS:**

**Roland Kupers**
Advisor Complexity, Resilience
Associate Fellow SSEE, Oxford University
**info@rolandkupers.com**

**Sara Heinrich**
Teaching Coach
**heinrich.sara@googlemail.com**

ELLEN MACARTHUR FOUNDATION
**info@ellenmacarthurfoundation.org**

UWC
**info@uwcio.uwc.org**

IN COOPERATION WITH ib
**support@ibo.org**

1 Drake.J, Kupers.R and Hipkins.R, Complexity – a big idea for education? International School, Volume 19/2/2017

*Our world is full of complex causality; causal loops and spirals, events with multiple contributing causes, chaotic oscillations in the weather, the stock market, the ecology. Understanding complex causal systems is fundamental to navigating the contemporary world, yet complex causality gets no more than an occasional nod under the label of systems thinking…*
*…Awakening learners to these more complex patterns is half the battle. The other half concerns how easily we can overlook what's going on. Drawn to salient events, we may, for instance, never ask what keeps systems constant, miss problematic patterns that play out only now and again, and neglect possible causal influences far away in time and space. (Perkins 2014)*

## WHY COMPLEXITY MATTERS

*The whole is something beside the parts* – Aristotle Metaphysics 1045a

No education system sets out to teach reductionism, yet it is to a greater or lesser extent an emergent outcome. This is no accident as reductionism is an approach that presents an essential skill for making sense of the world and intervening in it. This programme way of thinking is strongest in the natural sciences, but permeates the entire scientific approach.

An assumption often not highlighted is that systems can only be reduced if they are linear or close to linear. From the earliest days of the intellectual exploration of our world, this limitation has been clear: Understanding systems necessarily implies exploring the place of the individual student in the system – and therefore both the emotional and the cognitive connections are essential.

How might education help students grasp the complexity of the systems surrounding us? How can education better equip them to recognise and respond in appropriate ways to the inherent complexity in environmental issues, disease epidemics, social media challenges, conflict on many levels (personal, societal, national, and international), lack of food security for many, or a financial crisis?

Deeply interconnected systems are everywhere and at all levels of scale. One thing these very different systems have in common is that they behave in ways that surprise. Their interconnected nature leads to emergent behaviour that is not obviously triggered by a single cause. This means that systems can trip across thresholds into sudden transitions and they can react disproportionately to seemingly small triggers, or transform as a result of influences from within the structure itself.

If we want our students to understand how complex systems work, and to develop the habits of systems thinkers, we need to change some key ways in which we introduce them to new knowledge. Familiar teaching approaches typically try to reduce complex systems into their parts so they are easier to understand. Then we tend to look for linear cause-and-effect relationships between these separate parts. When dealing with complex systems, doing this is a problem because it ignores the essence of the dynamic whole that makes the system what it is. We need to find new ways to keep the wholeness, while still making the parts accessible. Traditionally, we have also looked for students to demonstrate their understanding by giving us 'right' answers to every question we pose. This is another familiar practice we need to adapt as we help students build new habits of mind. They need lots of practice in the more contingent ('it depends') thinking that an understanding of complexity demands.

The field has developed a shared language for talking about complexity concepts and there is general agreement about the key characteristics of complex systems. Complexity science develops an increasing amount of tools relevant across disciplines that deal with complexity as it is. Most universities have complexity research programmes, across many disciplines. Although still sparsely represented at undergraduate level, we anticipate it will become an increasingly relevant competence.

The IB's organising mission of creating a better and more peaceful world requires students to understand the systems that constitute it and appreciate their place in different complex systems and how they affect those systems. This understanding of complexity directly builds on the importance of the triple focus of self-self, self-others and self-environment. Given the increasing uncertainty and complexity of challenges students are likely to face in their lives, learning about, and through complex systems, develops a critical appreciation for what remains unknown and is unknowable.

Our challenge is to find ways to equip our students with an appreciation, and tools to effectively explore, discuss and can come to grips with complexity. Some teachers are already exploring these ideas with their students and some would like to start. Here we describe a short course (seven modules of two hours each) to introduce complexity to DP students. We hope that the format of this sample curriculum lends itself to application in a diverse range of contexts, e.g. as a term-long course, content for two project days or a short course over a couple of weeks.

Discussions at UWC Mahindra in March 2016, involving students, staff, and a representative from the Ellen MacArthur Foundation, who had been trialling a systems thinking course since 2013, led to the first design proposal of this complexity module. It is intended to be enhanced by other innovation hub schools in the IB system, that are exploring complex systems education.

## STUDENT LEARNING OUTCOMES:

Through this module, students will aim to:

- Understand when ignoring complexity is a problem;
- Understand the potential and limitations of our knowledge of complex system dynamics;
- Gain the ability to bring a complex systems perspective to bear on problems of real societal importance;
- Gain a first appreciation of the triple focus: self, self with others, and self with interdependence to the world.

## CURRICULUM DESCRIPTION

### UNIT 1 - COMPLEX SYSTEMS

**Learning outcomes**

1. An appreciation that systems-thinking matters to how we perceive societal problems.
2. A first appreciation of the triple focus: self, self with others and self with interdependence to the world.
3. Become comfortable spending time with a problem, rather than jumping to solutions.

**Module design**

Introduce and co-create safe-space guidelines, such as active listening, and get the students to check-in with each other and settle into the learning space (see suggestions below). (5-10 min)

**Breathing exercise 1 – introduce the first of a daily breathing exercise.** Every day it will be expanded with an element of interconnection between the self and other systems. The aim is to introduce a physical and personal experience of systems.
Square breathing: With eyes closed, settle into comfortable position, breathe through the nose. Breathe in for four counts, hold breath for four counts, breathe out for four counts, hold breath for four counts. Continue for four cycles. Open your eyes. (4 min)

Begin with post-its and **a personal reflection on a challenge** that students might want to address within the next 3-5 years. It can be a challenge as 'small' as wanting to get up earlier in the morning or something as big as addressing obesity. (5 min)

(10 min) Quick sharing of the challenge: Students write their name on the post-it note and share the idea with one other person, then exchange post-its. The next person makes a quick note of their name on the back of the post-it note and exchanges the post-it with one other person. A dialogue could sound like: "Hi, I'm Cary, and I've just talked to Sara. Her idea is…" moving to "Hi, I'm John, Cary

just told me about Sara's idea which is…"

Purpose: Students start getting a sense of how ideas can travel in a complex system.

(15-20 min) **Simulation of complex adaptive systems**. Start with enemy/friend simulation <see resources> and hold debriefing discussion. Elicit what they notice about self-organisation, emergence, feedback, compound causality, non-linear effects of catalytic changes, difference between self and others' perspectives as well as other concepts from the glossary <see Appendix 1>. This offers students a direct experience of the fact that system level behaviour can be disconnected from what the individual agents in the system experience.

(Optional) Show a short film of bird flocking and a computer simulation of 'boids' (see resources: 2). Hold debriefing discussion reinforcing the point from the first exercise.

(10-15 min) Introduce the tragedy of the commons (see resources: 3). This classic case from 1968 describes how individuals will always take more from the commons than their fair share, absent external control. "Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons… As a rational being, each herdsman seeks to maximise his gain [and] concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another… But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy." (Hardin 1968 pp. 1244 – NB the gender-biased language is common in the 1960s). Hold a discussion on what the critical assumptions are for this to be true, and when it might not be true.

(10 min) Introduce the case of the Subak rice terraces (see resources: 4). This case illustrates how over a period of 1000 years, the farmers in Bali self-organised to manage the commons effectively. This offers a counter point to the traditional tragedy of the commons perspective.

(15 min) Bringing both examples together to understand some characteristics of polycentric, complex social systems in dealing with a 'commons'. Generalise with Ostrom's principles for avoiding the tragedy of the commons (see resources: 5).

(5 min) Introduce a journaling and reflection technique of your choice. Get students to capture their a) general reflections, b) questions that arise, and c) how their emerging understanding of complex systems is transferable to learning occurring throughout their subjects and extra-curricular studies.

(10 min) Conclude by connecting the material from the module to the learning objectives listed above. Then give students ten minutes for personal, silent reflection on their learning. Encourage them to connect their learning to the personal challenge they shared at the beginning.

Some student comments:

- Interesting questions that came up: Why do we thrive towards efficiency? How can we best study/solve problems of information asymmetry?
- Most important take-away: there is no one size fits all solution, there is often an underlying interdependence, it can be dangerous to jump to conclusions without considering all aspects.
- Keep combination of simulation and explanation.
- Beware of too much jargon, especially in the treatment of Ostrom's thinking.
- Being clear about aims of the session at the beginning.
- Being clear on how the personal challenge ties into the overall session.

## RESOURCES

**1 - Enemy/friend simulation:**

Set-up

- Choose an empty space of at least 3-5 m2 per participant, with no trip hazards
- Ask people to spread randomly in the room

Round 1

- Ask each person to choose an enemy. Don't tell anyone.
- Ask each person to choose a protector. Again, don't tell anyone.
- Instruct everyone after the start signal to move around the room in such a way as to keep the protector in a straight line between yourself and the enemy.
- After a minute or so, most people will find themselves towards the outside of the space.

Round 2

- Ask each person to choose two enemies; again don't tell anyone; in this round each of you is the protector.
- Instruct everyone after the start signal to move around the room in such a way as to keep yourselves as the protector, in a straight line between the two enemies.
- After a minute or so, most people will find themselves clustered in the middle of the space.

Debrief

- Ask people to describe what happened
- Enquire whether the outcome was what people had intended
- Ask about the relationship between individual (agent) rules and intention, and the collective (system) behavior.
- Questions the familiarity of something that collectively happens which is not individually intended.

**2 - Mick Maus, 30th Aug 2015, 'How do Boids Work? A Flocking Simulation'**
Video can be found here - **https://www.youtube.com/watch?v=QbUPfMXXQIY**

**3 - Tao Lee, 28th September 2015, 'The Tragedy of the Commons Explained'**
Video can be found here - https://www.youtube.com/watch?v=nzJmaJCx7-s

**4 - Steve Lansing, PopTech Iceland 2012, recorded and published by Alix Landmann 9th August 2013, 'Subak: Balinese Water Temples and Water Management'**
Video can be found here - https://www.youtube.com/watch?v=INKrR27Crqw

**5 - Big Think, 23 April 2012, Elinor Ostrom on 'Ending the Tragedy of the Commons'**
Video can be found here - https://www.youtube.com/watch?v=Qr5Q3VvpI7w

## BACKGROUND READING FOR TEACHERS

**6 - WBGBHForum, 25 June 2014, 'Elinor Ostrom Nobel Prize in Economics Lecture'**
Video can be found here - https://www.youtube.com/watch?v=T6OgRki5SgM&feature=youtu.be&list=PLYsd9cWZ9TFLIaAW0z1f0zdtwz6PR9oFY (from 14'30 to 45'30)

**7 -** Ostrom, E. 2009. *A Polycentric Approach for Coping with Climate Change, Policy Research Working Paper 5095*, The World Bank

**8 - Human4832, 18th Feb 2008, 'Garrett Hardin on the Tragedy of the Commons'**
Video can be found here - https://www.youtube.com/watch?v=g8yOamWq3a0

## UNIT 2 - COMPLEX OR COMPLICATED?

### Learning outcomes

1. Ability to distinguish between a complicated and complex system
2. Understand the concept of emergence
3. Exposure to the terms 'wicked problems', 'resilience' and 'adaptive'

Key focus for teacher:

- Experimenting with ways of consolidating conceptual understanding and definitions as the course progresses.

**Module design**

**Breathing exercise 2 – continue daily breathing exercise.**
During the hold phase of the breath after the inhale, picture the oxygen being transferred from the lungs to the blood, being conveyed throughout the body, being burned for energy and converted into $CO_2$, the $CO_2$ is conveyed back to the lungs and expired.
Square breathing: With eyes closed, settle into a comfortable position, breathe through the nose. Breathe in for four counts, hold breath for four counts, breathe out for four counts, hold breath for four counts.  Continue for four cycles. Open your eyes. (4 min)

(10 min) Start by revisiting the discussion of the first module on the difference between Hardin's 'Tragedy of the Commons ' and Ostrom's perspective, illustrated by the Subak case.

(10 min) Show the introductory video of the Complexity Academy: **'Complexity Science 1: Introduction'**
Video can be found here - https://www.youtube.com/watch?v=r-JiHyejpn8

(10 min) Introduce the distinction between complex and complicated– acknowledging that words can have many meanings in different contexts. Discuss the etymology of complex, from the Latin 'to braid'. So complexity is the science of braided, or interconnected systems.

(10 min + 10 min feedback) Based on a list of systems (which they should be encouraged to expand), let the students group to discuss in what sense they are complex or complicated:

Airplane, bird, bird flock, car, traffic, human brain, DNA, city, village, stock market, garden, language, multinational company etc.

- (10 min) Show video of Monderman's shared space in Linz (see resources), and a video of traffic in an Indian city. Suggest the students discuss the differences. Elicit the link to Ostrom's principles for effective governance of the commons from the previous session.
  *(Some principles are: Communication between some participants of the community; reliable information on costs and benefits (e.g. reputation); relevance of the commons to the individual; reciprocation perceived as important; entry & exit capacity; longer time horizon; agreed upon monitoring and sanctioning mechanism; memory of precedents in solving commons issues [i.e. stories and myths])*

(10 min) Introduce the idea of emergence – connect back to the Subak Water temples from Unit 1.

(10 min) Introduce the idea of resilience (in both robustness as well as the ability to learn from disturbance) with examples from the Rockefeller Foundation's 100 Resilient Cities programme.

(10 min) Silent reflection.

Some student comments:

- Clarify early the difference between complexity and randomness (How much of the world is truly random?)
- Embed the discussions on complicated vs complex throughout the whole course.

## RESOURCES

**Complexity Labs, 28th June 2014, 'Complexity Science: 1 Introduction'**
Video can be found here - https://www.youtube.com/watch?v=r-JiHyejpn8

**Lyall, Sarah. Jan. 2005. 'Road design? He calls it a revolution', The New York Times**
Story can be found here - http://www.nytimes.com/2005/01/22/world/europe/road-design-he-calls-it-a-revolution.html

**Complexity Labs, 5th March 2005, 'Systems Thinking 8: Emergence'**
Video can be found here - https://www.youtube.com/watch?v=pooxD8XF5Uw

BACKGROUND READING FOR TEACHERS

Homer-Dixon. T, *Complexity Science*, *Oxford Leadership Journal*, Volume 2, Issue 1, January 2011, V

## UNIT 3: SYSTEMS DYNAMICS AND REPRESENTATIVE AGENTS

**Learning Outcomes:**

1. Understand various intervention strategies in a system;
2. Appreciate the importance of mapping multiple scales and dimensions of a system;
3. Introduction to concepts of stocks/flows, time delays, feedback;
4. Appreciate the impact of the choice of a representative agent.

**Module Design**

**Breathing exercise 3 – continue daily breathing exercise.**
During the hold phase of the breath after the exhale, picture the $CO_2$ travelling out of the body into nature, mixing with the $CO_2$ in the atmosphere, being taken up by plants, broken down into oxygen and water by the energy of the sun through photosynthesis, and making it back to you for inhaling. Square breathing: With eyes closed, settle into a comfortable position, breathe through the nose. Breathe in for four counts, hold breath for four counts, breathe out for four counts, hold breath for four counts. Continue for four cycles. Open your eyes. (4 min)

Game – *Avalanche* (after Sweeney and Meadows *The Systems Thinking Playbook* and Ken Webster)

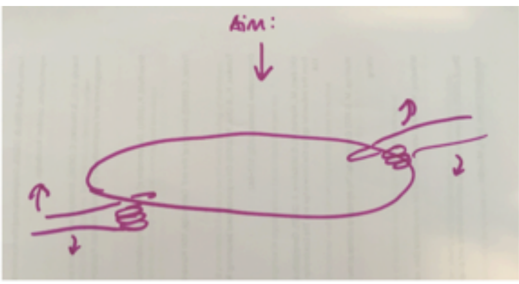
This reinforces the concept of system conditions and emphasises that it is sometimes necessary to change the rules of the game. Here, each team of about six people are given a collaborative task that is actually impossible, however hard they try to work together. Each team is given a cane or even better a hula-hoop. Note that it is essential that the cane or hula-hoop is light or else the effect does not occur as the pull of gravity drives the coordination, instead of the interaction. The team supports the hoop / cane at shoulder height by letting it rest on the topside of an outstretched index finger. NB: It must NOT be on the palm side – the point is that the hoop / cane rests on the fingers and cannot be gripped. The task is to lower the hoop / cane to the ground. But the rule is that if anyone loses contact with the hoop / cane the team must start again at shoulder height. The animator can ham it up a bit by challenging them to try harder, or saying “I did not expect it to last this long!”

Debrief the activity eliciting a discussion about the impact of the amount of people involved in the task, and introduce the idea of stocks and flows and their amount (reinforcing and balancing feedback). Also elicit the importance of systems conditions and enabling conditions, exploring how a change of rules would have changed the ease of achieving the outcome.

In discussion, highlight the learning point that if the **system conditions or rules of the game are stacked against a successful outcome**, no amount of good will or collaboration will be successful. Ask them **what rules or system conditions** need to be in place to make it possible (e.g. allowed to grip, only three people doing it).

Ask the students to visualise the system that emerged in the avalanche game. Look for the visualisations of feedback in the system, both reinforcing positive and balancing negative feedback.

A possible visualisation might look like this, with the arrows symbolising forces/feedbacks:



Show **this video**[2] of Peter Senge's talk at the Dalai Lama Centre for Peace and Edcuation [start at 37:00] of young children on the playground analysing the feedback flows that led to an argument.

Demonstrate the concept of stocks and flows as well as feedback loops using a vessel of water building on Meadow's bathtub analogy (Meadows, 2008: p 17).

Let students choose a 'wicked problem' that might be illuminated through a systems map and ask them to draw one. E.g. how can we avoid queuing at lunch time? How might we decrease food waste on campus?

Debrief and discuss the following or similar questions: What does the systems map help you see that you did not see before? What are some of the assumptions it relies upon? Are there people in your systems map? Do they appear in groups? What assumptions have you made about them?

Elicit the issue of the '**representative agent**' as a key limitation of systems maps, or 'stakeholder maps' – as they are sometimes referred to. When representing a group of people in a systems map, we need to map simplifying assumptions about them. Teachers might be characterised as hard-working, early-risers while some of them actually like to stay up late at night. Students might be seen as a group of hungry and lazy teenagers, even though we know that individuals are individual, and unique. They also change over time and depending on context. So a representative agent is really never representative of a whole group. One size fits none. Representative agents take differences and average them away. E.g. a representative human would have one testicle and one breast. This is not merely a problem of approximation – but goes far deeper than this. We will see that micro-diversity in agent behaviour is essential to understand the real-world behaviour of a complex system. Standard economics assumes representative agents i.e. every one reacts in the same way to economic signals. Making this assumption creates models with limited validity for the real world. Micro-fluctuations in wind turbulence and bird shapes is what defines the shape of a bird flock.

This does not mean that systems maps are not useful. They often visualise the interconnections of a system to a larger extent than we are able to see without them. They might be a good first step to identifying assumptions and building a foundation for testing them. Bottom line: Making assumptions is often necessary and may not be an issue, as long as you are aware of the simplifying assumptions.

Let students revisit the systems maps of their 'complex problem' asking them to make their assumptions explicit and re-draw their systems map if they need/want to. They may present their maps to the class and discuss them in the plenary, revisiting all concepts introduced in this module so far.

## RESOURCES

Sweeney, L. and Meadows, D. 2010. *The Systems Thinking Playbook* (White River Junction: Chelsea Green Publishing Co)

## BACKGROUND READING FOR TEACHERS

Booth Sweeney, L. Meadows, D. Mehers, G. 2011. The Systems Thinking Playbook for Climate Change – A toolkit for interactive learning (Eschborn: GIZ), accessible here: **http://klimamediathek.de/wp-content/uploads/giz2011-0588en-playbook-climate-change.pdf** - It has many of the same activities as the Systems Thinking Playbook but with an emphasis on Ecological framing.

Meadows, Donella. 1999. *Leverage Points – Places to Intervene in a System* (Hartland: Sustainability Institute), accessible here: **http://www.donellameadows.org/wp-content/userfiles/Leverage_Points.pdf**

Meadows, Donella H. 2008. *Thinking in Systems* (White River Junction: Chelsea Green Publishing Co)

Todd Rose, 2016. *The End of Average* (Allen Lane)

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2 Dalai Lama Center for Peace and Education, February 2006, 'Systems Thinking in a Digital World – Peter Senge', accessible on youtube: https://www.youtube.com/watch?v=Zs3ML5ZJ_QY

## UNIT 4 – NETWORKS

**Learning outcome**

1. Understanding networks as a way of conceptualising complex systems
2. Basic network literacy (nodes, edges, types of networks)
3. Introduction to concepts of phase transitions, small world networks, scale free networks

Key challenge for teacher:

- Make the link between networks and complex adaptive systems clear, i.e. how a static representation of a network can illuminate the nature of dynamic, adaptive behaviour.

**Module design**

**Breathing exercise 4 – continue daily breathing exercise.**
Now combine both exercises, imagining the internal process in the body during the hold phase after the in-breath and the external process in nature during the hold phase after the out-breath. Square breathing: With eyes closed, settle into a comfortable position, breathe through the nose. Breathe in for four counts, hold breath for four counts, breathe out for four counts, hold breath for four counts. Continue for four cycles. Open your eyes. (4 min)

Start with a network simulation with the students: In the first round, students are asked to pick two others (without disclosing them) who will be part of their network. The next task is to move around the room, attempting to put themselves and the two others into an equilateral triangle. After a minute or so, everyone is invited to sit down. Everyone is then instructed to stand up when one of his or her two other connections stands up. The teacher touches a random student on the shoulder to stand up, and a chain reaction follows. The entire class will stand up with one to two taps on the shoulder.

Debrief: What happened? What would happen if everyone picked only one other? What about three others? It depends. Simulate these scenarios to get a better understanding about the structural differences of the systems emerging.

Introduce network concepts of nodes and edges. Discussion of basic types of networks, illustrated with examples (e.g. Kevin Bacon number, obesity, terrorism, Facebook…).

Introduce scale-free networks and why they are relevant in many ways. Discuss how scale-free networks are resilient towards random attack, but quite vulnerable to targeted attacks, based on examples such as terrorism, network of species/biodiversity on our planet etc.

Reset the initial network simulation with the original rule (of students trying to form equilateral triangles with the people they are following). This time intervene as a teacher. Take one student away from the group and then reintroduce them. Test it with another student to see how the system behaves differently. Did the system reach a tipping point or more or less keep its original structure?

Watch an extract of **Robin de Carteret's 'Edge of Chaos Games'** here: **https://www.youtube.com/watch?v=3rZDNHtYxBI** (31:00 – 36:00). Discussion of network behaviours such as phase transitions, non-linear responses, tipping points, and resilience, illustrated with examples.

Follow with a basic network theory lecture which introduces the basic concepts such as nodes, edges, degrees. Using examples, this shows that not all networks are the same. Small world networks and scale-free networks are introduced, and their properties discussed. A connection is made to complex systems more generally, and systems in nature in particular.

### RESOURCES

Complexity Labs, '*Network Theory introduction*'. Accessible here: **http://complexitylabs.io/course/network-theory/**

**http://www.networkpages.nl** has a very extensive set of references, examples, and simulations.

### BACKGROUND READING FOR TEACHERS

- Christakis, N. A. & Fowler, J. H. 2007. *The Spread of Obesity in a Large Social Network over 32 Years*, New England Journal of Medicine, 357 (4), 370-379 July.
- Keefe, P.R. *Can network theory thwart terrorists*? New York Times, March 12, 2006
- Robin de Carteret's DIF session, '**Edge of Chaos Games**'
  Video can be found here - https://www.youtube.com/watch?v=3rZDNHtYxBI
- Marten Scheffer. 2009. *Critical transitions in Nature and Society*. (Princeton: Princeton Studies in Complexity)

## UNIT 5 – WHY MODEL?

### Learning outcome

1. Give students hands-on experience with simulation through Agent Based Modeling (ABM).
2. Appreciate that there is no 'solution' to a complex systems problem.
3. Understand 'Sugarscape', a canonic example of ABM for exploring economic inequality.

### Module design

**Breathing exercise 5 – continue daily breathing exercise.**
Continue to combine both exercises, imagining the internal process in the body during the hold phase after the in-breath and the external process in nature during the hold phase after the out-breath. However, add the awareness of other people in the room, who are also inhaling and exhaling, imagine how the gasses mix and are shared by all.
Square breathing: With eyes closed, settle into a comfortable position, breathe through the nose. Breathe in for four counts, hold breath for four counts, breathe out for four counts, hold breath for four counts.  Continue for four cycles. Open your eyes. (4 min)

(10 min) Recapture the learning of the previous lesson. Perhaps with this question: How might network theory help us grasp behaviours of complex systems?

(10-15 min) **Why model?**

Why do people model? Short introduction to the role of modelling in understanding socio-economic problems. Difference between simulations that aim to increase understanding of patterns with a full appreciation for what is unknowable, and models that aim to reduce uncertainty to come to an exact outcome. Discuss Epstein paper (or provide as pre-reading assignment if possible).

(10 min) Modelling with eggs and other things. Introduce and discuss Schelling segregation modelling without computers to demonstrate that it is about learning the dynamics of systems, not about IT or technology. It is just a tool to get to a better understanding of the dynamic of the system.

(Ample time) Introduction to NetLogo: model library, screen lay-out, turtles etc. Point out that many games use ABM (e.g. Simcity).

Hands-on modeling with NetLogo in groups of two:

- Open the '**Segregation Model**' from the library.
- Change parameters and see connection to the simpler egg model.
- What do we learn from the model?
- Get students to read the code and see if they can figure out how to alter certain aspects, e.g. the colour of the agents for example.
- Open **Sugarscape** from the library.
- Explain how Sugarscape simulates economic inequality in a highly stylised way. Discussion on how realistic this is. How useful? Alternatives?
- Change parameters (vary number of agents, metabolism, agent horizon) discuss outcome in the system.
- Depending on affinity, students may also change a few parameters directly in the code.

(10-20 min) Plenary. Return in a collective discussion to question the role of modelling in coming to grips with socio-economic issues. This might also lend itself to a brief discussion on why complexity science has gained momentum since the advance of digital technology and an increase in computing power in the late 20th century.

(10 min) Silent individual reflection, maybe about the use and limitations of models.

Some student comments:

- Some students really got a lot out of this, others seemed stuck with insights such as 'reaching equality is impossible'. Could we include examples of how ABMs are used to inform public policy decisions?
- Student: 'How do assumptions relate to culture and ideas?' Maybe include an exercise or discussion point that explores the notion of assumptions in more depth.

## RESOURCES

- Students should **install NetLogo** on their computers. (https://ccl.northwestern.edu/netlogo/)
- Epstein, J. 2008. *Why Model?*, Journal of Artific. Soc. and Social Sim., 11 (4). This is a delightful and short paper, highly recommended to give to students as reading.
- Random Economist. 2009. '*The Logic of Life: Racial Segregation*' by Tim Harford, accessible here: **youtube: https://www.youtube.com/watch?v=JjfihtGefxk**

## BACKGROUND READING FOR TEACHERS

- Schelling, T. *Dynamic models of segregation* Journal of Math. Sociology 1. 1971.
- Buchanan, M. *Meltdown modeling - Could agent-based computer models prevent another financial crisis?* Nature, 460 (6), August, 2009.
- The Economist. March 2014. 'Thomas Piketty's "Capital", summarised in four paragraphs', accessible here: **https://www.economist.com/blogs/economist-explains/2014/05/economist-explains**

## UNIT 6 - CONNECTING TO STUDENT'S PROJECT

**Learning outcomes**

1. Integrate the content of the module with the students' individual projects, CAS or project week experiences
2. Articulation of their project in the language of complex systems (agents, emergence, networks, resilience, modelling, phase transitions, tipping points, non-linearities...)
3. Experiment with different ways of mapping systems, and ways of identifying 'catalytic' nodes and interventions

Note:

Alternatively, to the suggestion below, this can be a session of 'assessed' presentations. Students choose their project in session two, develop a systems map for it in session three, create a network map in session four and a model in session five. This would be a nice way of continuous assessment.

Then they should look to find a model in the netlogo library that represents the nature of their challenge in some way:

**Module design**

**Breathing exercise 6 – continue daily breathing exercise.**
Continue to combine both exercises, imagining the internal process in the body during the hold phase after the in-breath and the external process in nature during the hold phase after the out-breath. Include the awareness of other people in the room, who are also inhaling and exhaling,

imagine how the gasses mix and are shared by all. Add the awareness of human activity in industry burning fossil fuels, which puts additional CO2 into the atmosphere.
Square breathing: With eyes closed, settle into a comfortable position, breathe through the nose. Breathe in for four counts, hold breath for four counts, breathe out for four counts, hold breath for four counts. Continue for four cycles. Open your eyes. (4 min)

(10 min) Recapture key learning from the last session on Agent-Based-Modelling. What questions do students now have for complex issues such as the spread of HIV/Aids?

(20-25 min) Model the application of the learning from the course to a 'wicked problem' that occupies you as the educator. In the piloting of the course, the circular economy framework was introduced as a result of seeing the economy with all its resource, energy and information flows as a complex system. How does complexity come to play in the framework? What points of intervention does it see in the current economy system to create a more restorative and regenerative model?

(15-20 min) Individual working time. Students reflect on their chosen project/challenge/issue, following these three guiding questions:

a. In what aspects is your project/challenge a complex system? Create a systems map for it.
b. How might you create an ABM for it?
c. Which different catalytic change or interventions can you imagine toward a desired outcome?

(15-25 min) Group work. Students form groups of three. Each student gets some time to explain their issue, its systems map, and thoughts on the other questions. The other two listen and then ask questions and give feedback on the systems map and possible interventions or 'solutions'. The group then moves on to hear from the other two.

If there is time, it might be good if students can respond to the challenges of their peers, improve their maps and presentations, and then present again to two different challengers.

(20 min) Plenary. Presentation to the whole class of a limited number of cases (2 or 3?), leaving sufficient time for collective discussion and exploration. What are the key aspects that are recognisable? What new questions does this suggest? How might the tools that have been presented be helpful? What irreducible uncertainties are likely to remain?

(10 min) Silent reflection time.

Every individual could then prepare a paper on their specific project, for submission and grading after the end of the module.

Some student comments:

- - "I think marketing is also crucial because it reinforces ideas about what types of food are pleasurable to consume. Is it possible to modify this model in a way similar to the washing machine system? Instead of companies constantly needing to sell more and more of their product in order to continue making profits, is there a way to make them accountable for the health of consumers and so incentivise the production of convenient, healthy foods?"
- -But what if consumers had different demands? And if companies could continue to profit by meeting these demands? Can a food system be made regenerative? When thinking of health, we typically think of reduction. Is it possible to frame it in a positive light? A circular diet...

## BACKGROUND READING FOR TEACHERS

Anderson, V. and L. Johnson. *1997. Systems Thinking Basics – From Concepts to Causal Loops.* (Acton: Leverage Networks, Inc.)

## UNIT 7 - A CRUDE LOOK AT THE WHOLE

**Learning outcome**

Learning about complex systems is not a linear process, so the purpose of the last unit is to revisit the elements covered in the previous units: Making connections, integrating with the students' projects, interests and intuitions. This will serve the learning outcomes of the complexity module as a whole:

- Understand when ignoring complexity is a problem
- Understand the potential and limitations of our knowledge of complex system dynamics
- Have the ability to bring a complex systems perspective to bear on problems of real societal importance
- Gain a first appreciation of the triple focus: self, self with others, and self with interdependence to the world.

**Module design**

**Breathing exercise 7 – continue daily breathing exercise.**
Final exercise – combine the internal process in the body, the processing of $CO_2$ in nature, other people and animals sharing the gases, human activity producing additional $CO_2$ and nature absorbing some of it in the oceans. Concentrate on sensing the web of interconnection, the gentle pull and push from the network connections.
Square breathing: With eyes closed, settle into a comfortable position, breathe through the nose. Breathe in for four counts, hold breath for four counts, breathe out for four counts, hold breath for four counts. Continue for four cycles. Open your eyes. (4 min)

10-20 min). Recapture the whole course. This could be done by co-creating a mind-map of different concepts and terms learned, and how they relate to each other.

Cover the following aspects. The dominant stance of science in education is reductionist. Breaking things into their parts to make the ideas more accessible has been a major ingredient of effective learning strategies. This approach has deep roots, but can be traced to the period of the Enlightenment at the end of the 18th century in Europe. It is best illustrated with the following quote by the French physicist Laplace: *"Assume an intelligence that at a given moment knows all forces that inanimate nature as well as the momentary position of all things of which the universe consists, and further that is sufficiently powerful to perform a calculation based on these data. To it, nothing would be uncertain. Both future and past would be present before its eyes."*
(Pierre-Simon Marquis de Laplace, Treatise on celestial mechanics 1799). The basic idea that reality is ultimately knowable has permeated the Western scientific model, well beyond the physical sciences. For example, much of DNA research holds the implicit promise that with full knowledge of the code's significance, life can be fully understood.

In effect, without it ever being a learning goal, or perhaps ever being mentioned, students have been taught reductionism as a core methodology for tackling problems. The organisation of the curriculum has also been reductionist, breaking knowledge up into subject silos that typically remain unconnected from each other. With the emergence of complexity science these familiar education practices are being re-evaluated, opening opportunities to reconnect the natural, the social sciences, and the arts.

We emphasise that complexity science does not reject a reductionist approach. The aim is simply to acquire the skill to decide when a reductionist approach is fit for purpose, when it is not, and what the tools are for those kinds of problems. Complexity science does not offer solutions to every difficult problem. But there is continuous progress and more importantly there is every indication that it will feature prominently during the adult lives of students who are in school today.

(10-15 min) Ask students to create a list of key characteristics of complex systems. Then feedback and compare them with the following list. Which aspects need to be added? Which are the most important insights? Which challenge our current 'way' of educating the most?

Complexity takes a biological systems view of the world. There is an emphasis on interconnections between the various system components. The following concepts are central to knowledge of the characteristics of complex systems and how they behave:

- . The whole is more than the sum of its parts.

- . The greater the diversity (heterogeneity) of the different parts in a system, the more resilient it is likely to be.
- . Systems evolve dynamically over time, self-organise and their global properties are said to be emergent.
- . Change is non-linear and properties are emergent, so small consequences can have large effects that might not have been anticipated or predicted.
- . There are constant interactions between any system and its surrounding environment so the boundaries of a system are typically 'fuzzy' – it is said to be open.
- . Understanding the dynamics of networks and their topologies becomes essential for many social and natural sciences.
- . Uncertainty: some things are knowable, but others are irreducibly uncertain. Embracing uncertainty and dealing with ambiguity become essential skills.
- . Agent Based Models are increasingly used to understand how system level properties relate to the individual agent behavior within them.

(20 min) In pairs, ask students to develop a list of 'habits of a systems thinker'. Which key ways of thinking and looking at the world do we need to adopt in order to see complex systems around us. After 15 min, hand out habits of a systems thinker sheet and ask them to add the ones they have come up with that are not yet covered.

Some topics in the current curriculum include some complex systems concepts. Examples are evolution and equilibrium. However, ideas about complexity are not typically foregrounded when addressing these topics, nor are ideas about complexity exploited across disciplines. Complexity science requires these concepts to be embedded into a rich new conceptual framework.

With this background, explore the following questions with the students:

1. Revisit the discussion of the first unit
2. Distil behaviours of a systems thinker
3. Discuss how causality is different in a complex and a complicated system
4. Where else would a complexity perspective be helpful?

(10 min) Silent reflection. Ask students to focus on questions they now have. You might also ask them to make a personal action plan of an area they want to focus on, key actions they want to take, and help they might need as a result of this introductory course. How do they want to further their learning?

## RESOURCES

Waters Foundation. '*Habits of a systems thinker*', Accessible here: **http://watersfoundation.org/systems-thinking/habits-of-a-systems-thinker/** – what would you add? See critically?

## BACKGROUND READING FOR TEACHERS

World Economic Forum's *Perspectives on a Hyperconnected World - Insights from the Science of Complexity*

## FURTHER TEACHER RESOURCES

Project GUTS: **http://projectguts.org**

Complexity labs: **http://complexitylabs.io/**

Waters Foundation: **http://watersfoundation.org**

## CONNECTING TO THE DISCIPLINES THROUGH CASES:

1. **Languages and literature**
   '**The Last Question**' by Isaac Asimov: **http://www.physics.princeton.edu/ph115/LQ.pdf**
   This short story explores the human condition and the question of entropy, highlighting the brittle nature of boundaries of complex systems. It lends itself to a discussion about energy flows in complex adaptive systems.

2. **Individuals and societies - Economics**
   **Topic**: Inequality. Use the subject of income inequality to demonstrate how a complexity perspective on an economic issue is different than the neo-classical perspective. The take away learning is intended to be that the classical economic models of the standard economics curriculum are useful tools, but that the toolset generally is insufficient to 'solve' real-world issues. Solving those issues requires adding elements from other disciplines such as history, geography, anthropology, philosophy and the humanities.

   **Topic**: The relationship between the economic model (tool) and policy. Taking an issue like climate change or poverty, explore the relevant economic models and look at policy examples. Discuss the gap between model and policy reality. Highlight the assumptions that underpin the economic model and whether they fit the real world. Describe how to frame and apply necessarily limited models to real world situations.
   **Resources**:

- **Arhur, Brian (2013) Complexity Economics: *A Different Framework for Economic Thought*, SFI WORKING PAPER:** 2013-04-012: This paper provides a logical framework for complexity economics. Complexity economics builds from the proposition that the economy is not necessarily in equilibrium: economic agents (firms, consumers, investors) constantly change their actions and strategies in response to the outcome they mutually create. This further changes the outcome, which requires them to adjust afresh. Agents thus live in a world where their beliefs and strategies are constantly being 'tested' for survival. These beliefs and strategies themselves in a large part shape the world in which they are tested. Economics has largely avoided this non-equilibrium view in the past, but if we allow it, we see patterns or phenomena not visible to equilibrium analysis.
- **Complexity Academy course on complexity economics: http://complexitylabs.io/complexity-economics-course/**
  This course is an overview to the new area of complexity economics, the application of models from complexity theory to the domain of economic science.
- **Colander , D. and Kupers, R (2014), *Complexity and the Art of Public Policy*, Princeton University Press**: This book describes how economics lost complexity and how this has shaped public policy. Adding a complexity frame back in, opens up new policy options that are usually eliminated from the debate.

3. **Sciences**
   **Topic**: the History of Science and Alexander von Humboldt.
   **Resources**:
   E.g. *The Invention of Nature – Alexander von Humboldt's New World*, by Andrea Wulf
   It might be equally interesting to bring a complexity perspective to the deisng of the Group 4 project.

4. **Mathematics**
   **Topic**: Network theory: small world and scale-free networks
   **Resources**:
   **Complexity academy module on networks**
   Graph theory see e.g. **https://www.youtube.com/watch?v=ZHqQDA3be-k**

5. **The arts**
   T.b.d

**Technology**
   **Topic:** Design thinking or human factors design
   **Resources**:
   **https://www.ideou.com/pages/design-thinking** – IDEO is a consultancy that specialises in design thinking.
   Human factors design at Bell Labs **(https://www.americanscientist.org/libraries/documents/20057611634_306.pdf)** is a classic review of AT&T's early research into making telephones easier to use for people, which still influences smart phone design today.

6. **Philosophy / Theory of knowledge**
   **Topic**: Reductionism, determinism and complexity. Discussion of direct causality and emergence
   **Resources**:
   Why should science-have the last word on culture? **(https://aeon.co/essays/why-should-science-have-the-last-word-on-culture)**

## APPENDIX 1: GLOSSARY

**Circular Economy** is a framework that describes 'an economy that is restorative and regenerative by design, and aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.'[3]

**Complexity** defies simple definition. Broadly speaking, complexity is about the study of Complex Adaptive Systems made up of interacting, interdependent agents that follow simple rules and influence one another and their environment. These interactions cause the agents involved to co-evolve with their environment. MIT physicist Seth Lloyd provided (at least) 31 definitions of complexity as noted by science writer, John Horgan in an essay called from "Complexity to Perplexity."[4] A complex system is one that cannot be analysed using standard analytic technology. That's because the interactions and interrelationships are so multitudinous and changing that standard equations can't capture them. More specifically, a complex system is made up of interacting, interdependent agents that influence one another and their environment. These interactions cause the agents involved to co-evolve with their environment. Generally, complexity science assumes that the evolving rules are simple rules—but that's an assumption—the rules themselves could be complicated, so there can by many layers of complexity.

**Design thinking** is defined by IDEO's CEO Tim Brown as a 'methodology that imbues the full spectrum of innovation activities with a human-centered ethos'[5]. He describes it further as a "team-based approach to innovation" featuring "endless rounds of trial and error." The designer uses their

sensibility and methods to match people's needs with 'what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity.'[6]

**Emergence** is the arising of novel and coherent structures, patterns and properties during the process of self-organisation in complex systems.[7]

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3 The Ellen MacArthur Foundation, 2015. Visual dictionary of the circular economy portal. **http://www.circulareconomy.com**
4 Horgan.J. (1995). From complexity to perplexity. Scientific American, 272(6), 104-109.
5 Brown.T. 'Design Thinking' in Harvard Business Review, June 2008, p.86: **https://www.ideo.com/images/uploads/news/pdfs/IDEO_HBR_Design_Thinking_9.pdf**
6 ibid.
7 Goldstein, J. ***Emergence as a Construct***: History and Issues, Emergence: Complexity and Organization (1999), 1 (1): 49–72. Emergent patterns are also discussed in Ibid. 1, p. 15 on pp 116 and further.

**Phase transition** is a term used in physics to describe the transition from solid to gas or liquid state. These transitions are sudden, triggered by a threshold value in temperature or pressure. In complex systems the term is used more generally (and loosely) to describe similar sudden transitions.

A crowd suddenly transitioning from a smooth state to a stampede is an example.

**Tipping point** is a term made popular by Malcolm Gladwell's best-selling book with the same title. It describes the point at which a phase transition occurs. The term sometimes leads to over focusing on the transition point, at the expense of understanding the dynamics of the system in the phase leading up to the change.

**Resilience** is the capacity of business, economic and social structures to survive, adapt, and grow in the face of change and uncertainty related to disturbances, whether they be caused by resource stresses, societal stresses, and/or acute events.[8]

**Uncertainty** "...must be taken in a sense radically distinct from the familiar notion of risk, from which it has never been properly separated... The essential fact is that 'risk' means in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomena depending on which of the two is really present and operating... It will appear that a measurable uncertainty, or 'risk' proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all."[9]

**Systems dynamics** has been defined by researchers at MIT broadly as an approach that aims to understand "how all the objects in a system interact with one another."[10] It studies how objects and people in systems interact through feedback loops, examining how changes in one variable affect other variables over time, and in turn the original variable.[11]

**Wicked problems**: A wicked problem is a problem that is difficult or impossible to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognise. The use of the term 'wicked' here has come to denote resistance to resolution, rather than evil.[12]

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8 Ibid. 3 p. 15 on pp 27.
9 Knight, F. H. Risk, Uncertainty, and Profit. Boston: Hart, Schaffner & Marx. (1921).
10 MIT Systems Dynamics in Education Project. 1997. https://www.ideo.com/images/uploads/news/pdfs/IDEO_HBR_Design_Thinking_9.pdf
11 ibid
12 Source Wikipedia