Complexity – a big idea for education?

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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)

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. 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 is increasingly developing tools relevant across disciplines that deal with complexity as it is. Our challenge is to find ways to equip our students with these tools, and this theory, so they can come to grips with complexity. Some teachers are already exploring these ideas with their students and some would like to start – in this paper we discuss the potential relevance of complexity science to the IB curriculum and present various strategies for integrating it in the programme. These issues will form the basis for the discussion at the IB pre-conference in October 2015.

The promise of complexity science

> "*Some scientists will seek and develop for themselves new kinds of collaborative arrangements; that these groups will have members drawn from essentially all fields of science; and that these new ways of working, effectively instrumented by huge computers, will contribute greatly to the advance which the next half century will surely achieve in handling the complex, but essentially organic, problems of the biological and social sciences.*" (Weaver, 1948)

Methods of scientific research that address complexity began to be developed by the Santa Fe Institute from the mid-1980s. These methods are now a mainstay at PhD and post-doctoral levels at most universities around the world. However the roots of the ideas are much older, as the quote by the physicist Warren Weaver illustrates. He identified the limits of the standard scientific approach for many of the important problems of the time, and he laid out a path for addressing their complexity.

The science research community failed to meet Weaver's hoped for window of 50 years from 1948. But complexity science does now have a substantial impact in both the natural and social sciences. It is also starting to influence policy and is gaining access to the imagination of the general public through a stream of popular science books. In the social sciences complexity has always been recognised as central, but new research tools provide opportunities to deepen ideas in the social sciences themselves, to reintegrate the social sciences with economics, and to connect them to the natural sciences.

Complexity research methods are gaining traction at national and international levels. For example the World Economic Forum has published a very accessible brochure entitled *Perspectives on a Hyperconnected World - Insights from the Science of Complexity.* In the Netherlands complexity has been proposed as one of the core themes for scientific research. Singapore has made it a strategic theme for the country and founded an ambitious new research institute.

Key ideas about complex systems

We've already noted that the need to use new pedagogies to introduce students to knowledge in general. Another implication of the growing importance of complexity approaches is that we need to *add* knowledge of complexity to the curriculum – i.e. there is new 'content' or understanding to address. In this section we briefly outline the scope of that content.

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.

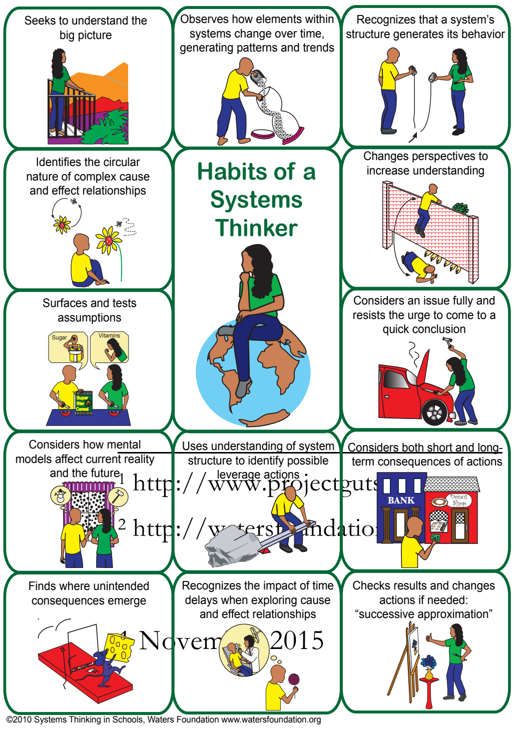
Some topics in the current curriculum include some complex systems concepts. Examples are evolution and equilibrium. However ideas about complexity are not typically foregrounded when addressing these topics, nor are ideas about complexity exploited across disciplines. Complexity science requires these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

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. 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 emphasize 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.

The state of systems learning in K-12

"*Unfortunately, little of the conceptual power embodied in the rapidly developing perspectives and tools of complex dynamical systems or informatics has informed the educational experience of our citizenry at any level, save that of graduate students in a few scientific areas.*" Jacobsen and Wilensky (2006)



Momentum is building to integrate complexity science into K-12 curricula. Jacobsen and Wilensky (2006) describe the implications for education. Perkins (2014) highlights how complexity requires revisiting how we teach cause and effect. The GUTS [1] (Growing Up Thinking Scientifically) effort, an outreach programme of the Santa Fe Institute, is exploring how to do this in practice.

The Waters Foundation[2] in the USA and NTO-effekt[3] in the Netherlands are other organisations that have

[1] http://www.projectguts

[2] http://watersfoundatio

pioneered the use of systems dynamics approaches in education. In particular the Waters Foundation website has a very extensive set of tools and resources. They have developed programs and rolled them out at scale, fostering networks of teachers. The Waters Foundation publishes a chart that succinctly summarises their approach. This is useful early complexity thinking, which offers a wealth of tools and practices to introduce the students to systems.

SFI's GUTS (Growing Up Thinking Scientifically) has developed detailed curricula which are available through their website. Deployment is currently mostly limited to schools in the US and summer programmes at the Santa Fe Institute itself, but the modules are detailed and shareable. All programmes are centred on practical cases such as water or climate change. The approach is cognitive, in the tradition of STEM (science, technology, engineering, and mathematics) education.

There are undoubtedly opportunities to build on these programmes, to leverage the long experience of systems dynamics curricula, as well as the experiences of individual teachers. This includes going beyond the cognitive, to experiential and intuitive learning – connecting complexity with tools such as CASEL[4] (Collaborative for Academic, Social, and Emotional Learning**)**. Goleman and Senge (2014) have argued persuasively that empathy for others and for the world is an essential element of engaging with complexity; personal development is an integral part of the ability to be a systems thinker. A group of schools in Australia is currently working with Harvard's Project Zero to develop thinking routines that allow exploring complexity.

Why the IB is so well placed

The good news is that IB programmes already contain a wealth of opportunities to explore complexity and complex causality. There are holistic threads that connect programmes throughout the IB continuum of education (illustrated here).

Together, they create a rich environment that includes the following elements:

[3] http://www.nto-effekt.nl

[4] http://www.casel.org

- The organizing mission of creating a better and more peaceful world necessarily includes the elements of personal development and empathy mentioned above. A complex aim that encompasses the need to lift the human spirit and avoid a 'tragedy of the commons'.
- Centred on learners within a curriculum that is broad, balanced, conceptual and connected
- One that actively encourages connections across disciplines and explores content significant to local and global contexts
- Effective approaches to teaching that carefully nurture the learner profile and develop the approaches to learning skills
- Learning experiences that build understanding by encouraging students to challenge their thinking, the source of their knowledge and their perspectives on the world

Via these types of opportunities, the IB programme has developed a community of schools rich in innovation and experience who are well placed to explore complexity.

Student capabilities

As we have already noted students need to build new types of knowledge about the features of complex systems and how they behave. They need lots of practice in thinking through how systems dynamics might play out in a specific case. This takes a disciplined blend of critical and creative thinking: critical because they need to look beneath the surface of things for hidden connections; creative because they need to look beyond the obvious to find non-linear links and interactions; and disciplined because this is not a case of 'anything goes'. Complex systems might behave unpredictably but they are bounded by the reality of their parts and dynamics. Students also need to set aside familiar habits such as expecting that there should be a right answer to every question asked. Actually they need to become good at asking questions and finding problems. No one can make them do these things so building the disposition to tolerate uncertainty and keep on exploring and building critical connections is really important.

When students use a specific combination of knowledge, skills, attitudes and values (dispositions), to achieve a specific type of action, we could say they have demonstrated competence in that aspect of learning. This is how the OECD describes 'key competencies' for example. Our preference is to use the term capability because it points to something more open-ended. What do we want our students to be capable of? How do we plan to stretch their existing levels of competence? Who do we want them to be and become? These are important questions because, as we've already noted, there are important non-cognitive dimensions to systems thinking. If we want students to be able to do the things outlined above we have to add a concern for their 'being' to the traditional focus on students' knowing and doing. How we might do this is an important pedagogical question to explore together.

Strategies for integration into the IB programmes

> "*It will be a delight to respect the natural system learning capabilities of students, instead of hammering it out of them.*" An IB teacher.

We should not try to integrate opportunities to learn about and practice complex systems thinking into the IB programmes in a top down fashion. Doing that would not be consistent with the insights of complexity science itself, nor with the experience and common sense of educators. Instead this should be an exploratory journey, capturing and sharing learnings from a diverse set of bottom-up initiatives, continuously evolving the approach.

Content, contexts and complexity

The content and the contexts that we choose to explore will either invite or inhibit complexity. We need rich, relevant content that students can immerse themselves into in order to explore connections, to be challenged by perspectives and experience the ambiguity that is at the heart of knowledge making. Taking a problem such as climate change, traffic congestion, or the spread of social norms as its focal point, students can be introduced to the tools of complexity science and practice them. This would allow the use of elements from many of the traditional disciplines. This approach could sit within a discipline and build connections out, or it could cross disciplines to connect and transfer understanding. A third solution might be a multidisciplinary approach that builds connections at need, irrespective of disciplinary boundaries.

Project GUTS at the Santa Fe Institute has pioneered the latter approach with many schools and they have gained a wealth of practical experience. They can offer a rich array of tools and practice. Our own programmes offer a wealth of opportunities for rich content: programmes of inquiry, conceptual understanding, inter-disciplinary units, projects, exhibitions, global engagement, service, action, group four projects; an ever expanding list. Each example brings an opportunity to understand that complex causality is both challenging and real; it is the very essence of the world we live in.

Thinking and doing

In building students' capacity to apply and transfer their understanding perhaps there is also merit in getting straight to the intellectual work that complexity thinking needs to do as we help our young people learn how the world works. They will need to build an understanding of some of the key properties and patterns of complex systems, indeed of the very concept of complexity itself. These ideas could be introduced via the Theory of Knowledge or Approaches to Learning components of the curriculum, or they could be integrated into topics that are already taught.

Rich topics have the benefit of supporting students to see what the ideas of complexity science mean in actual cases. What does it really mean to say that system properties are emergent? How do patterns of self-organization and behaviour emerge in a complex system? (How does the 'whole' system function in ways that go well beyond rules and behaviours of the individual agents in the system?) What might complex causality look like? (Can we recognise instances where amplifying or absorbing effects are in action? What are examples of resilience or fragility, and where have we already seen unexpected impacts over both distance and time?) What causes complex systems that often appear to be relatively stable to tip over into a phase change? Teaching students to reason about causal complexity and recognize patterns of complexity would complement more traditional explorations of curriculum content. This reflects the emphasis on developing understanding rather than replication of knowledge within an IB education.

When teaching problem solving a number of concepts and tools specific to complexity science could also be introduced. This would make the tools of complexity readily identifiable and let the students make the connection to problems in different disciplines. For example, the advent of fast processing power and accessible modelling software allows students to create and explore agent-based models of their own. In this way they understand how simple rules can lead to surprising and apparently complex emergent behaviour. Just as importantly, they will understand that models are also limited, that they are representations of the rules programmed into the software and not the real world.

The ideas sketched above suggest there could be multiple paths to exploring complexity within the IB curriculum. We look forward to developing these multiple paths through the experience of teachers.

Notes and references

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