Classroom as Complex Adaptive System (CAS): Credible framing, useful metaphor or mis-designation?

Abstract
This paper discusses the legitimacy of framing school classrooms as complex adaptive systems (CASs) with the aim of advancing discourse about the extent to which systems within education can be usefully designated as complex. Perspectives differ on criteria for applying a complexity framing to human systems, a consequence of the lack of any single definition of complexity theory, or agreement on the framing of CAS in human networks. However, the literature on complexity and education appears to both open (ajar) and close the door on descriptions and theoretical treatment of classrooms as CASs, and as a site for complexity-sensitive empirical research. The paper begins by presenting an overview of complexity discourse with respect to education, articulates conceptual framings for CAS and classrooms then moves on to advance the principal arguments in opposition to a conception of classrooms as CASs. Arguments from those in the field who are receptive, albeit tentatively, to applying a CAS lens to classroom systems are then explained. The paper concludes that whilst these arguments have merit, the legitimacy or otherwise of framing classrooms as CASs hinges to some extent on how both classrooms and CASs are framed. Finally, a primer is presented for an empirical complexity-sensitive classroom study undertaken in July 2020, findings from which will be published later this year.

Introduction
The aim of this discussion piece is not to attempt to definitively resolve the question of whether analysing classrooms with reference to CAS theory has utility, but to explore the arguments and signpost possible ways forward. The contribution this discussion makes to the field is that in arguing the case for theorising school classrooms as CASs the door may open to more empirical studies of classroom learning from a complex systems perspective, throwing new light on teaching and learning. I present arguments about the nature of classrooms in full appreciation that every classroom is different (a fact which in itself forms a central aspect of any discussion about classrooms as complex systems) and that as such, generalisations may be ill-advised. Where I do generalise, I refer largely to school classrooms as conceived and structured in western liberal systems of education which, whilst diverse in many ways (not least linguistically), share sufficient structural similarities to tolerate an inductive treatment. Where I use the term classroom, I am not referring to a room, but a system of approximately thirty pupils and one teacher occupying a designated physical space for the purposes of teaching and learning. A more detailed definition for the purposes of this paper is outlined in a later section.

Complexity and Education – where are we now?
Complexity Theory (CT) is a transdisciplinary conceptual framework applied to analysis of a range of dynamic, non-linear systems offering alternative schemes through which to view system change. Originating from disciplines such as thermodynamics, computer science, cybernetics, chaos and the natural sciences (see e.g., Holland, 2006; Lewin, 2000; Kelly, 1994; Gell-Mann, 1994; Kaufman, 1993), CT has been used since the mid to late 20th century, and more recently in the social sciences (Byrne, 1998, 2013; Mason, 2008; Sawyer, 2005), as a tool for understanding systems whose adaptation, system learning and change is resistant to explanation using traditional scientific method, or as Newell (2008:5) puts it, ‘phenomena resistant to reductionist analysis.’ CT breaks with linear, causal or deterministic explanatory frameworks (Morin, 2006), rejecting a version of reality in which ‘a knowledge

of inputs is adequate to predict outputs' (Davis and Sumara, 2006, p.11). In the social sciences, CT has been applied to the domains of organisational behaviour and change, sociology, health and social network analysis and is increasingly considered a useful tool for understanding how people operate within groups and how human systems change over time.

CT has also been employed as a lens through which to analyse systems in and of education for a little under three decades now examining, among other things, curriculum (Doll, 1993, 2002, 2008; Osberg & Biesta, 2008), educational research (Radford, 2008; Haggis, 2008; Kuhn, 2008; Davis & Sumara, 2006) purposes of schooling (Osberg, Biesta & Cilliers, 2008), educational change (Mason, 2008; 2009) and the philosophy of education (Morrison, 2008). Common conceptual markers unifying these and other related sources of discussion on complexity and education are firstly, their agreement that since system change is to degrees emergent, self-organised, networked and causally non-linear, the 'what works' epistemology (see Biesta, 2010) of singular causation prevalent in education policy-making will always be insufficient. Secondly, and following from the first point, since many of the antecedents to classroom learning are tacit, networked, multicausal and therefore difficult to model, any conception of observable educational outcomes and attributable causes (at any nested level within a system) are held extremely loosely, if not thrown out altogether. This renders probabilistic discussion about best practice, both general and local, problematic to say the least. Thirdly, the purposes, practices and outcomes of education must be scrutinised at system level and across levels of nested systems, making it sit uncomfortably alongside the fascination with measurement of individual learning, so prevalent in western education systems. To an extent, authors on complexity and education have so far got away with these obvious counterpoints between complexity thinking and prevailing portrayals and cultures of education because, as Koopmans and Stamovlasis (2020) point out in the inaugural issue of this journal, to date almost all writing on the topic has been concerned with theorising education as innately complex, rather than actually researching it. Invaluable theoretical groundwork has been done, resembling a drawn-out theoretical feasibility study; and now Koopmans and Stamovlasis' (2020) call to build on this foundation with more empirical educational research with a complexity framing is welcome and timely.

However, since CT is both at odds with the prevailing 'what works' paradigm in educational research (Biesta, 2010) and onerous to investigate, considerable challenges exist for those aiming to build on these foundations. Considering Schulman's (2004, p.504) assertion that education is 'perhaps the most complex, most challenging, and most demanding, subtle, nuanced and frightening activity that our species ever invented', Mason's (2014, p.7) notion that complex systems should be examined 'from as many angles, levels and perspectives as possible' and Jacobson, Levin and Kapur's (2019) assertion that neither qualitative or quantitative methods are sufficient to capture the dynamics of education systems, it may be unsurprising that complexity-sensitive empirical research in the field of education is scant. Despite these obstacles, and the absence of a clear consensus concerning the goals of educational research, it may be time for educational complexivists to build on the now substantial theoretical foundations and meet the challenges of complexity-sensitive field research head on.

Defining CASs

Much theoretical heavy lifting in complexity and human systems has been done over the past few decades, however, one area of theorising where there is still work to be done is in tightening-up the framing of CASs. Since the objective of this paper is to use CAS as an instrument of analytical comparison with classrooms, a definition of CAS is necessary.

However, beyond what is self-evident from the name (a system with complex characteristics which adapts itself) there is no single, sovereign definition of CASs upon which to draw. Whilst descriptions of CAS properties in the literature overlap considerably, the lack of any unified CAS field of study (or single body of literature) has proved an impediment to achieving a universally applicable CAS framing. Despite Holland's (1994) correct assertion that 'Among those who have carefully compared different CAS, there is little doubt that they form a coherent subject matter' (p.332), currently a wide range of CAS attributes are emphasised variously across domains as diverse as immunology, economics, nursing, education, city planning, business leadership and neuroscience, to name a few. Some authors emphasise certain CAS qualities whilst others omit them entirely, seemingly according to what is most applicable in their field. As Sullivan (2009, p.5) points out, 'it seems every theorist has his or her own list of characteristics, qualifying properties, or optimal conditions for complex adaptive systems, each slightly different from the next'. The cross-overs, gaps, duplications and divergences evident in the literature illustrate the problems in attempting to pin down CAS to a single definition. In the absence of a universal CAS conception, Holland's (1994) challenge, to provide a rigorous treatment of the range of CASs found across multiple domains, remains somewhat elusive.

Some however, have attempted to consolidate divergent definitions into more generalisable specifications for CASs (Holland, 1995, 2006; Sullivan, 2009; Carmichael & Hadzikadic, 2019; Preiser et al. 2018; Wilson, 2016), however, even in synthesised forms there is considerable divergence from one framing to the next. Examples of these include: Holland (1995, 2006), who presents a model for conceptualising emergence within dynamic systems and identifies seven CAS features. Preiser et al. (2018), who synthesised literature (including Holland, 1995, 2006) on CAS attributes into six different organising principles which bring about CAS behaviours. Chu, Strand and Fjelland (2003) who identified their own six common denominators of CASs, which overlap to some extent with Holland and Preiser et al. Whilst several of these depictions of CAS properties intersect, the absence of an agreed nomenclature for describing CASs, (theorists employ different terms for the same phenomenon or use shared terms for qualitatively different phenomenon) makes aligning them a challenge. As Gell-Mann (1994, p.17) pointed out 'Even the term CAS has different meanings for different researchers', partly explaining this with the light-hearted observation that 'a scientist would rather use someone else's toothbrush than another scientist's terminology'. Ricca (2012) also rightly notes that in any list of CAS properties, the individual properties themselves are mutually influential, so understanding them as atomised, distinct descriptors is not possible. Some higher resolution CAS definitions include long lists of properties which can be difficult to reconcile with other similar lists. Others have taken a lower resolution (zoomed-out) approach and presented definitions consisting of fewer, more overarching characteristics which, due to their generality, are more widely applicable. Sullivan (2009) for example, presents just four guiding characteristics for CASs (well-networked, non-linear, bounded and synergistic). Ricca (2012) adopts three 'inter-related hallmarks' (growth, mutual influence and non-linear connectedness). Wilson (2016) suggests that CASs fall into two broad categories: CASs which adapt at system level and CASs comprised of agents that employ adaptive strategies. He explains the distinction between these two interpretations positing that merely containing agents which adapt is no guarantee that a system will adapt.

Davis & Sumara, (2006), Mason (2008), Morrison, (2008), Radford (2008), Sullivan (2009), Newell (2008) and Ricca (2012) among others have drawn on CAS framings from complexity sciences to describe and discuss CAS features in the field of education. Though no agreed definition has emerged from these syntheses, similarities in their depictions indicate some coalescence around a number of underlying attributes which I posit are captured usefully by Davis and Sumara's (2006) list of necessary qualities for complex phenomenon:

1. Self-organisation: complex systems/unities spontaneously arise as the actions of autonomous agents come to be interlinked and co-dependent.
2. Bottom-up emergence: complex unities manifest properties that exceed the summed traits and capacities of individual agents, but these transcendent qualities and abilities do not depend on central organisers or over-arching governing structures.
3. Short range relationships: most of the information within a complex system is exchanged among close neighbours, meaning that the system's coherence depends mostly on agents' immediate interdependencies, not on a centralised control or top-down administration.
4. Nested structure: complex unities are often composed of and often comprise other unities that might be properly identified as complex – that is, as giving rise to new patterns of activities and rules of behaviour.
5. Ambiguously bounded: complex forms are open in the sense that they continuously exchange matter and energy with their surroundings (and so judgements about their edges may require certain arbitrary impositions and necessary ignorances).
6. Organisationally closed: complex forms are closed in the sense that they are inherently stable – that is, their behavioural pattern or internal organisations endure, even while they exchange energy and matter with their dynamic contexts (so judgements about their edges are usually based on perceptible and sufficiently stable coherences).
7. Structure determined: a complex unity can change its own structure as it adapts to maintain its viability within dynamic contexts; in other words, complex systems embody their histories – they learn – and are thus better described in terms of Darwinian evolution than Newtonian mechanics.
8. Far from equilibrium: complex systems do not operate in balance; indeed, a stable equilibrium implies death for a complex system.

Drawing on these properties, I define CASs as: *Context-sensitive, inherently stable systems containing multiple autonomous, interacting agents, whose inter-relationships create networked, non-linear behaviours from which self-organised system-level adaptation emerges*. Given the evident challenges in defining CASs, I submit this definition as an imperfect, but hopefully useful, point of reference for analysis of school classrooms. Later in the paper I organise and discuss Davis and Sumara's (2006) properties according to their classroom applicability.

Defining 'classrooms'

Hardman (2010) asserts that classrooms are 'sensitive, dynamic and resistant to accurate description'. However, as previously stated, whilst classrooms the world over are far from identical, they are characterised by certain physical and purposive structural similarities. These include (usually) one teacher leading multiple learners through some form of syllabus in spatiotemporal contiguity. In this paper, classroom refers to the physical space within which teachers and learners operate, as well as the teachers and learners themselves. Classrooms have atmosphere and ethos created by the interconnectedness of their inhabitants and degrees of structure governing behaviours. These are universal, but they vary by degree from one classroom to another. Classrooms are purposive environments in that they share a universal objective; that of educating learners. Not included in the classroom framing for this discussion are online classrooms or lecture-style classrooms, where interaction is typically minimal. Recognising that each of the below characteristics will vary from one classroom to the next, for the purposes of this paper, a 'classroom' is framed by the following broad properties, typical of school classrooms in the United Kingdom (UK) and similar western liberal democracies:

- One or more teachers (adult(s)) and collection of learners (children, more numerous than the teacher(s)). A classroom collective (Newell, 2008).
- Occupying a shared physical space simultaneously.
- For the purpose of teaching and learning. A learning system (Davis & Sumara, 2006).
- According to some form of agreed syllabus.
- Undertaking learning orientated activities.
- Including interaction and collaboration.
- Where teacher to learner, learner to learner and learner to environment interaction is fostered.
- In which pupils have some degree of autonomy (of movement and decision making).
- An environment with an ecology, ethos and character (Morgan & Matin, 2014). Unities with personalities (Davis & Sumara, 2006).
- Within a framework of fostering measurable academic progress for learners.

A classroom, therefore, is considered to be the shared physical space, the agents within it, its purposive objectives and the ecology formed by interactions of these elements. Within this broad description characteristics will vary within and between classrooms. Though much of the above framing applies equally to classrooms at all age phases, the following discussion is undertaken with primary phase classrooms (ages 5-11) in mind.

Encouragingly, empirical studies have been undertaken into areas of education including school interventions (Wetzels, Steenbeek and van Geert. 2016), non-linear modelling for - education systems (White and Levin, 2016; Guevara et al. 2014) and agent-based studies at system, school and classroom levels (Ingram and Brooks, 2018; Kosta et al. 2016; Blikstein et al. 2008). However, original research in this field remains sparse. A number of studies have examined classrooms, focussing on tessellations between classroom systems and complexity characteristics, analoging pupil interactivity with the non-linear, ensemble agent behaviour characteristic of CASs. For example, Fong (2006) looked at the interplay of order and chaos in three kindergarten classrooms in Macau. Sullivan (2009) undertook case studies looking at emergent learning in three US high school classrooms. Burns and Knox (2011) modelled a classroom as a CAS looking at relationships between physical, environmental, cognitive and social elements and Johnson (2016) explored relationships between classroom climate, interactions, and student achievement in four North Carolina charter schools through a complexity systems lens. Despite these forays into empirical complexity educational research though, the discussion literature on applications of CT to social systems contains several cogent arguments against conceptualising classrooms as complex, the most significant of which relate to the scale of classroom systems and the necessarily centralised, regulatory control emanating from teachers, curriculum and other structures which undermine bottom-up self-organisation. These arguments will be explored in the next section.

Classrooms as Complex Systems – Cautions

Perhaps the clearest demonstration that caution is advisable when conceiving of classrooms as CASs is evident in the observation that almost no complexivists in the field have yet done so. With a few notable exceptions, education complexity research has stayed out of the classroom. One explanation for this might be that CAS thinking itself is 'a high-level abstraction' (Lansing, 2003, p.184) and complexivist researchers are few in the field of education. Another is that studying classrooms is hard, a point emphasised repeatedly by those who have researched teaching and learning. Eisner (1985, p.104) for example who described teaching as 'an inordinately complex affair'; and others, (Clarke and Yinger, 1987; Tripp, 1993; Woods, 1990) frame classrooms as full of uncertainty and unpredictability. For the considerable effort involved there may be few professional rewards, which links to a third possible reason why classroom complexity research is minimal; the presumption that there is nothing new to learn. My own motivation to study classrooms through a CAS lens springs from my prior experience as a teacher, observing how inefficient classrooms can be, how impenetrable learning can seem and how tangled, messy and interleaved causality is in teaching and learning. From this perspective, the idea that classrooms function optimally and that no new insights are likely to emerge from complexivist classroom research appears false. However, and this is conjecture, without first-hand experience of the complex world of school classroom teaching, it can appear as though the classroom entity is well understood and functions perfectly well. I would argue there is much we still have to learn, if we are willing to look in new ways. The vast majority of papers, philosophical and empirical, address larger systems within education, systems which are subject to regular review and fluctuation, including curriculum design, national or local school authorities or language as an educative medium. Where it features, treatment of the classroom entity is typically restricted to that of a nest within larger system analysis, a reasonable proposition given that according to many complexivists, a key characteristic of complex emergence is that it occurs in systems of scale (Cilliers, 1998; Holland, 1992, 2006; Carmichael & Hadzikadic, 2019; Goldstone & Sakamoto, 2002; Waldrop, 1992). The general trend has been to view the system-of-systems as the unit of analysis, rather than a single nest within the system-of-systems. Therefore, the first argument against conceiving of school classrooms as CASs concerns scale, or the lack of it. Scale in this sense refers not to the material size of the system, but to the number of interacting elements it contains.

The issue of scale

One explanation why arguments for complexity in education tend only to be made about large scale systems is that the descriptive power of complexity in social settings is borrowed from the computational sciences which deal almost exclusively with systems of great scale. Whether modelling economic systems, neurons or city traffic, a CAS characteristic is the sheer volume of agents. Common to all ascriptions of the label 'CAS' in nature (insect swarms, weather patterns, neural networks) and human connectivity (cities, economies, social networks) is the property that the system in question is large in scale, containing many interacting agents. New properties and behaviours emerge as a consequence of agent connectivity which requires sufficient agents to create sufficient possible connections. Whereas in the world of computational modelling of non-linear distributed networks a single agent might be a worker bee, a crypto currency coin or a water droplet, in the social sciences the single unit is the human and therefore complex adaptive social systems are necessarily large scale. In Weavers' (1948) depiction of organised and disorganised complexity, a fundamental characteristic in both iterations of complex systems is their tremendous number of parts. Snowden and Boone (2007) note that complex systems involve large numbers of interacting agents. Mason (2008) similarly argues that it is the incredible scale of a CAS which prompts its shift from linear to exponential orders of connectivity, and which therefore gives rise to emergence. Compared to an insect swarm or an internet social network, a school classroom containing approximately thirty pupils and one teacher is small scale and, based on Mason's analysis, not conducive to the myriad interactive permutations necessary for self-organisation or emergence. According to this argument, great scale is an essential system characteristic for complex behaviour. Miller and Page (2007) stress the point that complexity is a deep property of a system which is not present in merely complicated systems. The depth they refer to is a consequence of voluminous interactive moments between system agents, which arguably cannot not occur in small scale systems. Cilliers' (1998, p.3) description of complex systems begins with the assertion that they 'consist of a large number of elements.' Small systems, according to Cilliers, can be understood through conventional (linear) descriptions of agent behaviours, in which causes and effects can be separated and their outcomes controlled. However, it is only as agent numbers and their interactions reach orders of magnitude that systems take on the properties of complexity. Williams (2011) concurs that in complex social systems the irreducible nature of cause and effect is a consequence of their 'many interacting agents' (p.1036). Holland (1992; 2006), Carmichael & Hadzikadic (2019), Golstein & Sakamoto (2002) and Waldrop (1992) also all designate large numbers of agents as an essential property of CASs. These descriptions of the nature of complex systems lend considerable support to arguments against interpreting classrooms through a complexity lens, since according to these parameters, even with high levels of interactivity, a class of pupils is unlikely to contain sufficient agents for those interactions to undermine its inherent stability or qualitatively change its characteristics towards spontaneous self-organisation.

The relatively small-scale nature of school classrooms and their limited agent interactions are not the only, or most significant limitation on attempts to frame them as CASs. Many systems of much greater scale with far larger numbers of interacting parts are not complex. For example, The British parliament contains 650 members but does not behave in self-organising, emergent ways. On an even larger scale, the British Armed Forces has 150,000 active personnel but functions largely with linear predictability, not with distributed, edge of chaos spontaneity. CT only predicts complex, emergent system behaviours where local autonomous agent interactivity is high and information therefore moves bottom-up between agents and where organisation forms as a consequence of agents acting out of mutual self-interest, rather than flowing top-down through a hierarchy. It goes without saying that these system characteristics would render a parliament or a military unfit for purpose, but to a lesser extent the same assertion can be made about school classrooms. The second cogent argument against conceiving of classrooms as CASs therefore, concerns the sources of coherence flowing from their purposive structures which inhibit the sources of spontaneity necessary for self-organisation.

The purposive nature of education

Arguments have been made that a principal 'learning' characteristic of classrooms is their tendency towards self-organisation and self-maintenance (Davis & Sumara, 2006; Newell, 2008; Hardman, 2010). Some degree of self-organisation is inevitable in any system which is not entirely mechanistic and deterministic and since wholly determining the opinions, predilections, desires, impulses, thoughts and behaviours of groups of pupils is impossible (not to mention undesirable), the tendency for bottom-up self-organisation to exert some influence on classrooms is inevitable. But whether residual levels of self-organisation in an otherwise orderly system can be said to produce complex behaviours is unclear; unlikely, but currently still unclear. In conventional classrooms the top-down influence of the teacher imposes limits on self-organising behaviours and is a function of a universal classroom system characteristic which delivers a blow to comparisons with CASs. Classrooms are not morally neutral systems, they are values and goal-orientated. In complex adaptive social systems not subject to the regulatory influence of system-level values and goal-orientation, such as cities or social media networks, the self-organisation and its concomitant adaptation is the learning. The movement and interaction of many agents (be they citizens, cars or individuals on Twitter) all influencing one another, all influencing the system and being influenced by it, produces change which exceeds the individual possibilities of the agents. However, this analogy does not translate well into school classrooms because, as Biesta (2009) points out, education is not a morally neutral activity in which the ensemble organises itself spontaneously through the pursuit of individual self-interest. Instead, it is a purposeful one, with shared intended outcomes. Because of this, it matters what is learned. He argues that describing learning as whatever emerges as a result of classroom interactions ignores the fact that education exists so that people learn something, not just anything. This argument tessellates with others (Kuhn, 2008; Egan, 1997) that the CAS framework has considerable limitations when analysing classroom learning, since classroom learning is goal-directed and has prescribed objectives towards which teachers must steer pupils. As Kuhn (2008, p.178-179) puts it

> ‘It may be argued that there is a fundamental mismatch between complexity and educational enterprise as in essence complexity is descriptive whereas education is normative, or goal-orientated. […] complexity offers organisational principles for describing how the world and humans function. Education, however, is orientated towards achieving certain goals’.

Egan (1997) similarly implies that as well as goal-orientation, education (and by definition classroom learning) is value-orientated. The ‘musts’ in the following quotation are illustrative of the ethical and moral imperative implicit in this orientation.

> ‘[…] we must shape the young to the current norms and conventions of adult society, that we must teach them the knowledge that will ensure their thinking conforms with what is real and true about the world, and thus we must encourage the development of each student’s individual potential (p.3).

This description of the purposes of education is demonstrably incompatible with the common understanding of CASs, in which higher complexities may emerge as a consequence of lower order self-concerned autonomy. As Kuhn (2008, p.179) goes on to state ‘complexity merely describes, whereas education aims to make a difference.’ A consequence of this purposefulness which characterises education (and which distinguishes it from learning in a more general sense) is the centralised control of the teacher.

Teachers impose expectations and structures on classroom activity and do so in the interest of curricular aims and purposes. Biesta (2009) refers to this as teachers introducing ‘an asymmetrical element into the educational process’ which is ‘one of the main reasons why educational learning is radically different from collective, interactive, explorative learning’ (p.31). A significant point here is that without the imposition of purposive, values driven structures, the likelihood of emergent adaptations in knowledge states aligning with curriculum aims is low and the risk that nothing of curricular value will be learned, potentially high. Ramussen (2005, p.219) agrees that educational learning has ‘special intentions in mind’ and touches on this point about the probability of learning occurring by describing teaching as a 'social arrangement and organisation aimed at intensifying possibilities for learning and the results of learning'. In contrast to the moral neutrality of complex systems found in nature or in large social systems, the presence of overarching 'special intentions' in school learning weakens the case for classrooms being viewed as CASs, since their adaptive potential is held in check by hierarchical structures whose very aim is to keep the system well away from the edge of chaos states necessary to invite points of bifurcation, through which the system innovates.

The relatively small number of agents in typical school classrooms and the necessary degrees of top-down constraint and conscious organisation in pursuit of curricular goals make comparisons with CASs, with their spontaneous and disorderly dynamism, seem unrealistic. For bottom-up self-organisation to occur among pupils the network cannot be too centralised. Pupils need to be more widely connected within the network than is typical in many classrooms, where the teacher interacts with everyone, but pupils may only interact with a handful of immediate peers. According to the arguments above, the principal driver of system centralisation, curriculum goals, would need to become less prevalent and forces of randomness more prevalent for classrooms to take on the decentralised or distributed characteristics more conducive to self-organisation. Something that is not happening any time soon. However, CASs are not characterised by all-out chaos. There is organisation, there is constraint and there is balance between forces of coherence and disruption, and it is this interplay, evident to varying degrees in all classrooms that has tempted some researchers towards the idea of the complex adaptive classroom. The next section reviews some of the key arguments in support of this framing.

Classrooms as CAS – Possibilities

Davis and Sumara (2006) synthesised qualities necessary for a system to be considered complex, among which are several which can be applied without much hesitation to school classrooms. Table 1 arranges these qualities, along with Davis and Sumara's definitions and my own analysis of their classroom applicability. This analysis is presented for illustrative purposes, as a means of capturing general applicability, not for the purposes of granular examination of each quality in relation to classroom systems. Detailed arguments can, and should, be made about these individual complex qualities, evaluating their relevance to classroom systems. My suspicion is that the closer the inspection of classroom dynamics, the greater their applicability to the classroom will appear.

Applicability to classrooms as broadly defined in this paper	**Author commentary**
Applicable to classrooms	
Short-range relationships – most of the information within a complex system is exchanged among close neighbours, meaning that the system's coherence depends mostly on agents' immediate interdependencies, not on a centralised control or top-down administration.	*By far the busiest network of interaction traffic in classrooms is among pupils, usually decentralised, often operating in shifting topologies of smaller groups. Thoughts, ideas and perspectives interact continually.*
Nested structure – complex unities are often composed of and often comprise other unities that might be properly identified as	*Classrooms sit within phases, schools and communities, curriculum and subject; and*

complex – that is, as giving rise to new patterns of activities and rules of behaviour.	*are composed of small groups, individuals, individual brains etc.*
Ambiguously bounded – complex forms are open in the sense that they continuously exchange matter and energy with their surroundings (and so judgements about their edges may require certain arbitrary impositions and necessary ignorances).	*Information flows between nested levels within and beyond the classroom.*
Organisationally closed – complex forms are closed in the sense that they are inherently stable – that is, their behavioural pattern or internal organisations endure, even while they exchange energy and matter with their dynamic contexts (so judgements about their edges are usually based on perceptible and sufficiently stable coherences).	*Despite their openness to neighbouring systems and changes in agents etc, classrooms are stable unities over time.*
Partially applicable to classrooms	
Self-organised – complex systems/unities spontaneously arise as the actions of autonomous agents come to be interlinked and co-dependent.	*Despite considerable top-down structures, irrepressible classroom cultures/sub-cultures, moods, practices, uses of physical space, interactions, social behaviours and hierarchies inevitably shape internal organisation.*
Bottom-up emergent – complex unities manifest properties that exceed the summed traits and capacities of individual agents, but these transcendent qualities and abilities do not depend on central organisers or over-arching governing structures.	*Learning is networked, unpredictable, multi-variate, input-influenced but not input-controlled and a consequence of bottom-up as well as top-down factors.*
Far-from-equilibrium – complex systems do not operate in balance; indeed, a stable equilibrium implies death for a complex system.	*Classrooms fluctuate between sources of coherence and randomness throughout a typical day, continually moving between order and chaos.*
Marginally or non-applicable to classrooms	
Structure determined – a complex unity can change its own structure as it adapts to maintain its viability within dynamic contexts; in other words, complex systems embody their histories – they learn – and are thus better described in terms of Darwinian evolution than Newtonian mechanics.	*There are two broad organising principles at work in classrooms (centralised and decentralised). System structure tends ultimately to be maintained more by centralised than decentralised dynamics, thus limiting the capacity for a classroom to change its own structure. A point discussed later in the paper.*

Table 1 Applicability of Davis and Sumara's (2006) complex system qualities to classrooms.

A glance at Table 1 indicates that at the very least, arguments can be made for conceiving classrooms as complex unities. None of Davis and Sumara's indicators are entirely absent from classroom systems and only 'structure determined' can be considered marginally applicable. Hardman (2010, p.8) has made the general argument that descriptions of classrooms as 'sensitive, dynamic and resistant to accurate description' seems to fit with how teachers experience them, however there is a need for empirical studies to examine classroom systems more closely in relation to the depictions of complex phenomena in Table 1. In this section, I draw on analysis in Table 1 to explore rebuttals to the two central arguments discussed earlier: that the small-scale of classroom systems and their characteristic goal-driven, top-down configuration render comparisons with CASs untenable.

Small can be complex

Arrow, McGrath and Berdahl (2000) have attempted to address the issue of system scale by developing a general theory of small groups as complex systems. They contend that even small groups have several things in common with CASs and can behave in complex ways, depending on their composition and configuration. They emphasise that a small group does not denote just any collection of individuals, but that when comprised of 'loosely coupled, mutually interacting, independent members […] with a shared collective identity' (p.4) a group's diverse constituents, openness to the contexts within which it is embedded (and which are embedded within it) and dynamic nature make it best understood using the framework of CAS theory. One argument they make is that it takes considerably longer to identify emergent behaviours in smaller-scale compared to larger-scale systems, because smaller groups tend to gradually increase in complexity and produce emergent patterns over time. Another is that complex, global-level aggregate behaviours show themselves less obviously in systems with fewer agents. They argue that systems containing fewer agents do produce complex behaviours, however such behaviours are harder to recognise and take longer to unfold. This is significant and may go some way to explaining the paucity of complexity applications to classroom systems. Arrow, McGrath and Berdahl (2000) argue that if members see themselves as belonging to a group nested within a larger collective, if member activities are more closely interdependent within the small group than within the larger collective and if they share a 'common fate not totally shared by the larger collective' (p.35) then interactions between group members (who are themselves complex systems) are likely to produce complex behaviours. Classrooms certainly fit this description. They have a clear shared identity characterised by physical, organisational and socio-cultural factors. They both nest within larger collectives (year group, school) and contain nested smaller entities (table groups, triads/dyads, individual brains) and interactions cross these levels regularly. The classroom group changes over time as pupil relationships evolve, individual and mutual learning develops and socio-cultural cultures and subcultures unfold and evolve. This is evident in the observation that dynamics, interactions, relationships, motivations and knowledge states within a classroom are not the same at the end of a day, week, term or school year as they were at the start. Changes at classroom level also create emergence at institutional level, whereby the character, culture and learning of pupils in a class shapes a range of school-wide factors including systems and routines, policies of behaviour management, inclusivity and community engagement. Whether such changes at classroom level are sudden or radical enough to warrant a designation as 'complex', is a valid question. Sudden eruptions of novelty characteristic of CASs are probably rare in most classrooms, where incremental change dominates. Given Arrow, McGrath and Berdahl's (2000) argument that emergence takes time to reveal itself in systems containing fewer agents, it is possible that classroom complexity researchers would need to gather data over whole school terms, academic years, or longer, to identify qualitative system-level adaptations.

Conclusions from empirical classroom studies have noted CAS-like characteristics at classroom level. Doyle’s (1977) study of student teachers in their placement classrooms noted that pupil-pupil and teacher-pupil interactions, even at small group level, were characterised by simultaneity, multidimensionality and unpredictability. Dowson, Cunneen and Urwin (1999) examined pupil motivation in a large-scale longitudinal study and found that it was influenced by a networked array of personal, interpersonal, classroom and teacher factors, none of which could be isolated and inserted into a linear, causal equation to predict motivation levels. Instead, they concluded, because classrooms and their students behave in non-linear and adaptive ways, the system needs to be studied holistically. There is certainly evidence that even at their relatively small scale, classrooms display emergent behaviours characteristic of CASs. Newell’s (2008) exploration of complexity at classroom level suggests that complex emergence can be expected. He describes how topologies of networked interactions might change over the course of a lesson, beginning with centralised teacher transmission and moving towards decentralised or distributed networks of smaller groupings, characterised by short-range relationships from which bottom-up emergence is possible. Newell’s language is understandably tentative as he states that group work is no guarantee of emergence, but that the ’collision of diverse ideas and representations […] may lead to self-organisation’ (p.11). Newell’s suggestion is that the scale of the system is less important than the possibility for interaction, and that self-organisation is more a function of the density of idea collision than of the number of agents. This implies that given sufficient quantity and crowdedness of pupil utterances and perspectives, even a small-scale system can produce self-organising and emergent behaviours. However, as Carmichael & Hadzikadic (2019) point out, emergence only results from correlated interactions, in which agents affect one another, and one another’s behaviours and interactions. Holland (2006; 2014) refers to such interactions as ‘conditional’ in that agents continually send and respond to if/then signals through their interrelations; they interfere with one another as they interact. The type and quality of pupil interactions matters therefore, perhaps more than the density. Newell (2008) also argues that trans-level emergence is evident in classrooms. In challenging traditional notions of teaching and learning, a CAS lens draws attention to learning as a phenomenon occurring at more levels than just the individual. The small group learns because individuals learn, the class learns because the group learns (and vice versa), and the school learns because the classroom learns. This flow of information and influence between nested levels is a common institutional characteristic of classrooms and schools.

Miller and Page’s (2007) point that complexity is a deep property of a system, may be as much a function of the character of interactions as it is a function of scale or density. Davis and Sumara (2006) assert that in complex systems every agent (or node) is not a basic unit, but in fact a sub-network in its own right, connected to other sub-networks via short-range relationships, meaning that the depth of the system is a measure of its various levels of fractal self-sameness (brains, individuals, small-groups, classrooms, schools, communities, culture) rather than of the quantity of agents at a given level. Davis and Sumara (2006) posit that complex systems (biological and social) are scale-free (though the question of what may or may not be a scale-free network has been a topic of hot debate more recently, see Barabási, 2018), in that their qualities are evident (or self-similar) at all nested hubs of connectivity across their trans-level architecture. The extent to which classrooms can legitimately be designated as scale-free-like is debateable, as Newell (2008) notes, they tend to fluctuate between centralised and decentralised orientations, even within a single lesson. However, as

Davis and Sumara (2006) point out, this will depend to some extent on how they are organised. The argument that despite their small number of agents, classrooms can display complex adaptive behaviours is clearly not without merit. There is a consensus however, that emergence at classroom level is not automatic, but must be facilitated, or to use Davis and Simmt's (2003) term 'occasioned'. Some degree of each system quality listed in Table 1 is inevitable at points in a class of 30 pupils, however the extent of each is largely a function of how teachers configure teaching and learning, how competing organising principles are balanced and how sources of freedom and constraint play-out as a result. The next section considers how such occasioning might be facilitated in the context of a values-driven, goal-orientated system.

'Occasioning' emergence within the structure of teaching and learning

The prevalence of sources of coherence over sources of emergence driven by educational goals, has not deterred a few significant voices from applying the CAS framing when describing classrooms (Hardman, 2015; Burns and Knox, 2011; Newell, 2008; Dalke et al. 2007; Sullivan, 2009; Johnson, 2016). Studies have explored ways in which characteristics of school classrooms tesselate with descriptions of CASs, pointing out strengths and weaknesses in the utility of the analogies. Burns and Knox (2011) for example, compared De Bot et al.'s (2005) descriptions of the development of complex systems over time, with their own analysis of classrooms. They found a number of correlations, including that both consist of sets of interacting variables (pupils, teachers, resources, environment), both had unpredictable outcomes (learning outcomes, critical incidents), both are part of and connected to other systems (family, institution, community), both are sensitive to initial conditions, meaning that small changes or incidents can result in large differences over time and both develop to some extent through interaction and internal self-organisation. These qualities produce a degree of instability predisposing classroom systems to degrees of self-organisation and emergence over time (Burns & Knox, 2011). Davis and Sumara (2006) posit that to really understand the dynamics of the classroom it is necessary to stop thinking linearly, a point which is supported and explained, with reference to how the social world behaves, by Byrne (1998, p.20)

> 'Outcomes are determined not by single causes but by multiple causes, and these causes may, and usually do, interact in a non-additive fashion. In other words, the combined effect is not necessarily the sum of the separate effects. It may be greater or less, because factors can reinforce or cancel out each other in non-linear ways.'

An example of this in a typical classroom setting are the multiple factors which might determine whether a pupil contributes verbally or not to a class discussion. These might include (though are not limited to) peer pressure, personal ambition, knowledge of an answer, fear of failure, confidence level, social status, degree of interest or desire to go to lunch. Significantly, all of these factors are to some extent networked, insomuch as they are influenced by group dynamics and interactivity through feedback signals. The temptation to interpret participation or otherwise as solely a function of a pupil's confidence in relevant knowledge is understandable, but a CAS framing invites teachers and researchers to view such phenomenon as networked and multi-variate rather than linear and univariate. Guanglu (2012) suggests that the pervasiveness of modernist understandings which view the world as simple, linear and stable tends to disguise the non-linear, recursive nature of teaching and learning and discourage teachers and researchers from exploring ways in which classroom interconnections produce continuous recursions of understanding, interpretation, re-understanding and reinterpretation. A break with linear thinking is an invitation to acknowledge (and perhaps embrace) unpredictability, which can be both disconcerting for teachers and possibly undermining to the goals of teaching. However, unpredictability is causally connected to learning insomuch as randomness changes interactive behaviours, injects novelty into classroom interactions and bifurcations which can qualitatively alter critical classroom incidents and learning states.

Support for conceptualising classrooms as CASs is also derived from the fact that a classroom sits within a series of nested systems in which exponential patterns of behaviour emerge at higher levels due to local interactions at lower levels. These nests include education systems at the macro end and individual brains at the micro (see Ovens and Butler, 2016). Hardman (2015) asserts that unanticipated bifurcations of novelty are inevitable in classrooms partly due to their internal diversity, including the uniqueness of individual pupils' (and teachers') brains. Classroom systems are nested among, sit within and interact with other systems, including down to the neurological level. Taking the position that actions, interaction, responses and speech are embodied representations of neural activity, he draws on Cillier's (1998) model of the brain as a distributed network. To illustrate the important role that personal histories and experience play in how individuals respond to interactive learning situations, Hardman (2015) explains that 'the current state of a neural network when it receives new stimuli will influence how the network adapts' (p.123). This means that an individual's accumulated experiences to date and associated neural networks shape how he or she learns. Since all pupils in a given classroom have unique histories and environmental (emotional, material, linguistic) experiences prior to and outside of school, individuals have unique distributed neural networks which will respond to similar circumstances differently. Neural diversity therefore is one factor contributing to the diversity of perspectives, ideas and utterances which individual pupils bring to bear on collaborative classroom activity, and which create critical incidents. In interactive learning situations, individuals' neurological responses, embodied in speech or action, create counterpoints, presenting novel stimuli to which individuals' neural structures will respond. Any given stimulus has the potential to reinforce an existing neural pathway, or create new ones; this, according to Freeman (2000), is learning. As Young (2014, p.135) points out, 'the brain is a CAS. Essentially then, there are complex adaptive systems within the complex adaptive classroom.'

Described in these accounts of classrooms, and adding some legitimacy to comparisons with descriptions of CAS, are factors beyond, or resistant to, control. Despite the structure of organised schooling, the structure of curriculum and the necessary order imposed by teachers, diversity arising from the nestedness and openness of classroom systems creates opportunities (or leaks) for unpredictability and non-linear change. These characteristics also invite bottom-up, self-organisation, even where and when it is not intended. Accounts of learning arising from distributed, self-organised, environmentally sensitive neurological processes, which both introduce and respond to diversity within classrooms, correlate with depictions of classrooms as CASs. Bottom-up emergence via moments of bifurcation presents possibilities for novel understandings and new directions, in spite of teacher-imposed structures. This appears consistent with arguments that classroom learning is 'complex, historically contingent, non-linear and sensitive to context' (Hardman, 2015, p.148) and suggests that even in classrooms characterised by linear transmission and teacher control, openness is inevitable to some degree.

An example of non-linear emergence is evident in the common understanding that alongside the top-down influence of the teacher, as presenter and re-presenter of what is to be learned (Biesta, 2009), pupils also influence and change one another through their interactions (verbal or non-verbal). The flow of content, explanation and questioning does not only travel unidirectionally from teacher as hub towards pupils as nodes resulting in the development of predictable products of knowledge, understanding and skills. Alexander et al. (2009, p.178) point out that 'change that happens in the learner, be it dramatic or imperceptible, or immediate, or gradual, exerts a reciprocal effect on the learner's surroundings'. This depiction offers a positive correlation between classrooms and CASs, implying that there is also a feedback of information and influence between pupils, towards the classroom environment, the climate and back towards the teacher as well. As pupils change, they also change one another, the teacher and their surroundings, including the physical environment, through their mutual interconnectedness, much like the behaviour of agents in a CAS. Davis and Sumara (2006) refer to this phenomenon when stating that classrooms are systems which learn. Within such systems, they posit

> 'one cannot reliably predict how a student or a classroom collective will act based on responses in an earlier lesson, or sometimes a few minutes previous. In other words, strict predictability and reliability of results are unreasonable criteria when dealing with systems that learn (2006, p.18)'

The results referred to here might be pupils' utterances, grades, test scores, perspectives, understandings or answers. The argument is that making judgements about who will learn what in a given episode of teaching and learning activity is problematic. A consequence of this argument might be that too many variables are interdependent and co-influential for test results to be used as a reliable, principal measure of learning. The network of multi-directional causes and effects, including between pupils, between pupil and teachers and between all agents and the environment means that all variables are continually influenced by and influencing all other variables. This means that in a classroom, change (learning) is unlikely to only unfold entirely as intended or directed by the structures of organised schooling, the curriculum or the teacher. The system and its constituent agents will also adapt and change in ways not predicted or intended by those governing structures. Haggis (2008, p.165) suggests that emergence is always at least partly unpredictable, stating that 'what emerges will depend on what interacts, which is at least partly determined by chance encounters and changes in environments.' This offers some support to Biesta's (2009) point that learning cannot be reliably predicted but is judged retrospectively. Teachers may have learning intentions, but they do not reliably know what learning will occur. It can be described after the fact, but not accurately predicted in advance.

Clocks and Clouds: A middle ground?

Radford (2008) bridges arguments for and against comparisons between classrooms and CASs using a metaphoric continuum between what he refers to as 'clockishness' and 'cloudishness'. He draws on Popper's (1979) assertion that all systems can be viewed on a continuum between deterministic, reducible and predictable (clockish) on one hand, and indeterminate, unpredictable and open (cloudish) on the other. Radford's (2008) contention is that even the most deterministic systems, such as clocks, have degrees of unpredictability at the micro level, and that likewise, the most open and unpredictable systems, such as clouds, have some degree of predictability, at the macro level. Or, to explain it another way, at the right resolution a clock will reveal its lack of mechanistic causality and a cloud will reveal its causalities. All phenomena, according to Radford, can be thought of as having degrees of both 'clockishness' and 'cloudishness'. The question is, which is the most useful or accurate explanatory framework for depicting a given system. With this question in mind, some researchers have attempted to describe the 'cloudish' features of classrooms and how exploring them might lead to new insights about classrooms and classroom teaching and learning.

Semetsky (2005) presents a radical vision of a self-organised classroom, characterised by decentralised control, pupil autonomy and an absence of direct instruction. She posits that this would ‘naturalise the concept of learning’ (p.31) through the introduction of greater choice for pupils. She envisages a classroom in which there are no right or wrong responses or answers, just an array of choices for pupils, creating an environment with an ‘inherent incapacity for students to experience failure at any point within the process’ because there is no ‘special educative aim’ (p.31). This extreme cloud-like vision of classroom learning would require a radical overhaul of curriculum structures, possibly of the very purposes of education, and Semetsky acknowledges that this conceptualisation has the potential to be counter-productive. She draws on Cillier’s (1998) warning about chaotic system behaviours or ‘catatonic shutdown’ (p.119) and suggests that a multiplicity of pupil options may contribute to complete disorganisation rather than self-organisation. This is similar to Waldrup’s (1992) assertion that whilst frozen (clockish) systems can benefit from ‘loosening up a bit’, turbulent (cloudish) systems ‘can always do better by getting themselves a little more organised’ (p.295). Morrison presents a similar critique, and asks

> ‘whether self-organization is such a good thing, or whether it will lead to diversity, inefficiency, time wasting, mob rule, and a risk of people going off in so many different directions that the necessary connectivity between parts of an organization, its values and direction will be lost or suffocated’ (2006, p.7).

This is a valid question. Judging when sources of novelty and disruption risk overwhelming sources of coherence within a system is crucial to maintaining productive edge of chaos states and is a central aspect of teacher professional judgement. CASs maintain their equilibrium through spontaneous self-organisation, whereas, in a classroom it is largely due to the influence of the teacher. A key illustration of why the conception of classrooms as CAS both is, and is not, accurate and useful.

Others present visions of the classroom as self-organising adaptive systems which are less adversarial to the common purposes of education systems than Semetsky’s vision. Fong (2006) for example, suggests that the concept of self-emergent order is well suited to early learning environments because of their emphasis on child-centred pedagogies and resulting diminished centralised teacher roles. On balancing the ‘dual worlds of emergent order and imposed control’ (p.1) and the challenges teachers face in managing the latter in busy nursery or kindergarten classrooms, Fong posits

> ‘Pedagogy may be ‘invisible’ in kindergarten classrooms: the teacher structures the classroom but then stands back and allows the children to learn through self-organized discovery, experience and practical activity; there is a greater semblance of freedom, choice, and implicit control. The emergent order of the kindergarten classroom, modelled on invisible pedagogies, demonstrates the benefits of replacing conceptions of classroom control with those of creating the conditions for learning, emergent order and children’s self-organized learning’ (p.1)

The notion of invisible pedagogies sits in contrast to Berstein’s (1975) ‘visible pedagogies’, in which teachers noticeably impose order from the front. In Fong’s conception, teachers facilitate, observe and judiciously intervene; an approach more prevalent in early education classrooms than in later phases. There is some resonance with Semetsky's (2005) radical laissez-faire vision and also with Jörg's (2009) view of learning as generative, interactive and reciprocal, and teachers as fellow traveller or facilitator of learning, a conception roundly criticised by Biesta (2009) for its lack of realistic application to purposeful educational endeavour. Davis and Sumara (2006) point out that the prevailing centralised architecture of teacher-centred classrooms makes distributed pupil interactions, and the resulting possibility of self-organisation, less likely. By contrast, when pupils have opportunities to rely more on one another, to interact more and take more local responsibility, conditions are ripe for complex emergence and surprising learning and innovation might be fostered. Herein lies a tension however, between the potential benefits of more decentralised pedagogies and their risks. In flying the flag for what they call 'emergent lessons', Dalke et al. (2007) acknowledge that classrooms which develop more spontaneously will be at odds with the current educational climate.

Conclusion

In this paper I have explored the utility of school classroom analysis through a CAS framing, presenting two cogent arguments for caution as well as counter arguments. There are grounds for applying CAS analysis to school classrooms, however it is apparent that fit-for-purpose judgements about CAS classroom framing depend to a large extent on the particular CAS and classroom definitions employed. Some conceptions of CASs clearly lend themselves more readily than others as a lens for conceptualising classrooms, just as certain classroom conceptions may be more or less compatible with different characterisations of CAS. Attempting to compare two such apparently unfixed entities may seem like a fool's errand, however to some extent this serves as a marker of where the field has got to so far. If the considerable potential of complexity thinking is to be realised in education such messiness may have to be tolerated in the short-term. Classrooms the world over will always (I hope) be different, but complexity classroom framings will (I also hope) grow in clarity, consensus and legitimacy as empirical research increases.

Classrooms have the potential for complex behaviours, but the extent to which they can reliably be described as CASs is less a function of a 'natural state', than as a function of how teachers configure them. Critics of the complex adaptive classroom idea may argue that the goal orientation of the educational project necessitates top-down, centralised regulation which eliminates the possibility of classrooms fully realising CAS-like qualities. However, accounts in the discussion literature and from the limited number of empirical studies suggest that even the most stringently centralised classrooms contain sufficient 'cloudishness' to invite elements or moments of self-organisation. Noting a range of CAS-like classroom behaviours is not, in itself, evidence that classrooms are CASs. However, it seems reasonable to conclude that all of Davis and Sumara's (2006) properties may be evident in all classrooms at some point, to some extent. Emergence can be occasioned in classrooms by means of managing enabling constraints such as task design, seating arrangements, group composition, time management, pupil autonomy and establishing decentralised and distributed structures. Can classrooms be reasonably and usefully conceptualised as CASs? That depends. Considering the evidence that learning depends on a mixture of direct instruction and autonomous discovery, a more appropriate question than 'are classrooms CASs?', might be 'to what extent and in what ways can teachers encourage the qualities of complexity in their classrooms, and what are the consequences?' If the consequences of encouraging qualities of complex emergence are useful, in the current educational climate, the question might be 'are teachers brave enough to do so?' In the face of increasing high stakes, outcome driven managerialism in British and similar education systems, I echo Dalke et al.'s (2007) call for new arguments for the efficacy of interactive and more distributed teaching approaches. With the theoretical foundations for complexity in education now thoroughly explored, it is likely that new arguments will only emerge from empirical findings. Considering the central role that classrooms play in education, it seems unlikely moving forward that the credibility of complexivist educational arguments can be upheld without complexity-sensitive classroom-based research which seeks to move beyond complexity framings as an interesting metaphor, towards understanding teaching and learning towards the 'cloudish' end of Radford's (2008) continuum.

A primer for up-coming classroom-based complexity-sensitive research.

The final section of this paper presents an overview of a complexity-sensitive classroom study undertaken in 2020 which aimed to deliberately create conditions which might 'occasion' emergence in a British primary classroom and explore the consequences. Data from the study is still being analysed and will be presented in a future publication. The aim of presenting this overview is to illustrate one empirical approach to researching complexity at classroom level.

Locating the edge of chaos in a British primary classroom: A complexity-sensitive classroom research project.

The study in question was undertaken in a single year 4 (n=30 8 and 9-year-olds) classroom in a one form entry school in the southwest of England. Framed as a complexity-sensitive, mixed methods (Poth, 2018) case study, the research took place over one week during which pupils engaged in a one-off project designing, constructing and testing model rockets. The pedagogical orientation of the week was negotiated and co-constructed between researcher and class teacher and intended to explore the possibilities of more decentralised, networked pedagogies. The research questions were:

1. In what ways can learning be said to have 'emerged' within classroom activity?
2. What are the value, qualities and characteristics of 'emergent' learning?
3. What classroom and pedagogical conditions most readily encourage 'emergence'?
4. To what extent can a primary classroom be usefully described as a CAS?

Data gathered included pupil self-reported moments of learning (MoL), in which individual pupils recorded and articulated moments of personal insight, knowledge and skill development. This was complemented by video captured episodes of whole-class and small group activity, individual pupil interviews, researcher field notes and a teacher journal. Video data represented in sociographs depicts pupil interactivity and is analysed using social network analysis to generate insights about nodal patterns and their role in the emergence of learning at individual, group and whole-class levels. Pupil interview data will draw on MoL and be triangulated with video data to generate contextual insights about individual, group and whole-class learning. The teacher journal will be used to gain a teacher's-eye-view on the experience of planning for and applying decentralised pedagogies.

It is hoped that insights from this study about classroom pedagogy and learning will support articulations of new arguments for the value of decentralised teaching and learning architectures and for the utility of ecological conceptions of classrooms, in and beyond current educational paradigms. Broad preliminary findings suggest that

1. Sources of coherence and randomness must be constantly monitored and finely balanced to occasion emergence.

2. Learning at all levels occurs because of, in spite of and irrespective of what teachers do.
3. Interactions within and across nested hubs within the classroom system contribute to learning at all levels.
4. Viewing the classroom through a CAS lens enables teachers to develop more networked interpretations of classroom phenomenon, including group and individual learning.
5. Maintaining conditions of emergence requires comfort with uncertainty from teachers.
6. A CAS lens may encourage teachers to examine interactive group work more forensically, leading to surprising insights about occasions and antecedents of pupil learning.
7. Social dynamics among pupils are a significant emergent phenomenon which exert self-organised adaptations upon class systems.

In addition to these discussion points from preliminary data analysis, the study has helped highlight possible useful future research questions. For example, what can be learned about the non-linear characteristics of learning, such as time lags between sources of learning and critical learning incidents; and how do sources of learning jump across nested levels within the system? Future research will explore these questions.

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