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# Emerging from the Deep: Complexity, Emergent Pedagogy and Deep Learning

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# Emerging from the Deep: Complexity, Emergent Pedagogy and Deep Learning

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Abstract

As indicated in the title – *emerging from the deep* – this paper proposes that an ability to face and deal with complexity can emerge from deep learning that is facilitated by pedagogies designed to ensure this outcome, especially an emergent pedagogy that instills deep education. Educators would view the classroom as a complex adaptive system (CAS) capable of self-organizing and operating at the edge of chaos where order emerges, just not predictably. Self-directed students would experience a learning environment that is appreciative of nonequilibrium, unpredictability, shifting and emerging patterns, and co-evolution. Teachers would be coaches, activators and facilitators. Students would take part in learning encounters that ensure intellectual networking and conceptual connections. The knowledge and insight that develop would be interwoven and interdependent (complex), which is appropriate because complexity is needed to address complex problems.

## 1. Introduction

The profound complexity that learners will encounter after they graduate – even while in school – demands a pedagogy that respects complexity. This refers to an interlinked system (or network) of many different but interconnected parts that are tightly woven together. To complicate matters, these intertwined system parts tend to interact with each other in a myriad of ways making it difficult to understand, manage and change the system (Davis & Sumara, 2010; Mason, 2008). Learners will have to engage with complex personal, economic, health, political, social, cultural, ecological, and technological systems – local, national, regional and global. The title *emerging from the deep* reflects the idea that an ability to face and deal with complexity can emerge from deep learning that is facilitated by pedagogies especially designed to ensure this outcome. Fullan and Langworthy (2014) concurred that certain pedagogies can "find deep learning" (p. 6). As a caveat, the use of the term deep learning herein does not correlate with computer science's understanding that it connotes training artificial neural networks in artificial intelligence (see LeCun et al., 2015).

One such pedagogical approach is an emergent pedagogy (to be discussed in detail), which encourages people to reconsider the relationship between a classroom and the larger, very complex world. To develop this idea, herein the classroom is conceived as a complex adaptive system (CAS) where deep education can happen via emergent pedagogy. “Going deeper (learning emphasised by deeper learning) has [to become] celebrated and prioritised” (Briggs, 2015, para. 9). “What was once a pedagogical fantasy is now an indispensable necessity” (Briggs, 2015, para. 5). An emergent, deep pedagogical approach helps learners make connections within and between their academic studies and the real world. With depth of understanding and intellect, they will be better prepared to take on the complexities of contemporary society.

As a caveat, this is a position paper about the merits of achieving deep pedagogy and deep learning by employing complex adaptive systems thinking. No attempt is made to map its application or develop a plan for follow-up action. Rather, position papers enable a person to assert a personal statement about an issue and then use a well-reasoned argument to convince others that the idea has merit and is worth being adopted and implemented in the future (McGregor, 2018).

## 2. Complexity and Education

Because the world is incredibly complex, education must deal with complexity (Davis & Sumara, 2010; Mason, 2008). Complex is Latin *complexus*, “plaited, intertwined, interlaced strands, braided.” This compares to simplicity, Latin *simplus*, “onefold” (Harper, 2020). If complex means interconnected, then noncomplex (simple) means not connected, independent (Alvira, 2014). This etymological explanation is tendered, because people usually do not bring this particular distinction to bear on simple versus complex. Anything with onefold (simple) is much easier to address than something that is braided and twisted together (complex).

Issues facing humanity are deeply complex including unsustainability, climate change, loss of diversity, health inequalities, poverty, violence, and uneven income and wealth distribution. A powerful example at the time of writing was the Coronavirus COVID-19 global pandemic, which changed life irrevocably for the whole world. Memorization, recall, and rote learning (e.g., surface and shallow learning) are insufficient for such complex problems; deeper learning is required so people can delve into the very essence of these complex, messy, wicked issues. Distilling these issues down to their core (i.e., *going deep*) requires deep learning to unravel them and unwind the twisted elements making them so complex.

### 2.1 Complex adaptive systems

Davis and Sumara (2006) claimed that for an educational phenomenon to be classified as complex rather than noncomplex, it must manifest eight qualities and their attendant characteristics (see Table 1). Although others may use different terms for some of these features (Mason, 2008; Morin, 2008; Senge, 2006), Davis and Sumara's terminology does reflect the main aspects of a complex adaptive system (CAS) such as the stock market, an ant hill, a bee hive, or the climate. Generally speaking, CAS are inherently paradoxical. They are leaderless with no coordination, *yet* things still happen. Patterns emerge, *yet* no one was told or directed to make a pattern. They are governed by chance and randomness (stochastic); *yet*, those involved trust that something will emerge. If any element of the system is altered, the whole system reacts and adapts. What is created has none of the traits of the contributing agents; *yet*, they all created it (Code.org, ca. 2006).

### 2.2 Classroom as a complex adaptive system

The attributes in Table 1 apply to a classroom informed by complexity thinking. All classrooms are made up of a complex variety of learners. CAS theory assumes that the more variety there is in a system, the stronger the system. A CAS classroom would depend on ambiguity and contradictions to create new possibilities and move the learning in new directions (Fryer, ca. 2001). Within this "requisite variety" is connectivity whereby the connections and "relationships between the agents are more important than the agents themselves" (Fryer, ca. 2001, p. 3). It is through these relationships that patterns emerge, and learning evolves. In reference to Davis and Simmt's (2003) interesting pedagogical innovation, Davis and Sumara (2006) described a "knowledge-centered pedagogy [wherein the classroom] collective is understood as an intelligent entity" (p. 121). The diversity of learners and learning in the classroom creates many possibilities for sense making and more robust understandings.

CAS classrooms "are neither stable nor unstable [but] operate at the boundary between the two zones. [They exist] on the edge of chaos" (Dann & Barclay, 2006, p. 22; see also Kuhn, 2009). Complexity theory holds that chaos does not mean disorderly but rather order emerging, just not predictably. Chaos is not order missing; it is order coming into existence (Ireland, 2007; Kuhn, 2009). No more teacher as the sage on the stage with students as empty vessels waiting to be filled. Comprising teachers and learners, the CAS classroom would have open and closed boundaries within which powerful interactive dynamics unfold leading to the ability of educational actors to adapt, reform and reorganize without external control or guidance. This self-organization helps ensure that new

Table 1. Main Features of Complex Adaptive Systems (CAS)

| |
|---|
| **self-organized:** complex systems can spontaneously adapt without the need for external control or direction; the many actions of autonomous agents come to be interlinked and interdependent; change happens from within; new structures or patterns appear without a central authority creating them or an external entity imposing them |
| **bottom-up emergence**: properties manifest within the system that are greater than and exceed the capabilities and traits of individual actors with this occurring without central governing structures or organizers (i.e., no one person is in control) |
| **coherence due to short-range relationships**: rather than depending on top-down or centralized control, the system holds together (coheres) because of a mass of immediate exchanges between and among interdependent agents operating within the system; they bounce off of each other and create something bigger (holistic); what is created cannot be traced back to any one person (think of an ant hill); small, local actions lead to systemwide change often facilitated by leverage |
| **nested structure**: the complex system comprises interrelated entities that are also complex; this entangled arrangement leads to perpetually changing patterns and rules of behaviour; new knowledge and insights are embodied (owned by and become part of all involved) |
| **open, ambiguous boundaries**: the edges around complex systems are sufficiently open to allow a continuous exchange of matter, information and energy required for both coherence and self-organization |
| **closed, organizational boundaries**: edges around the system are firm enough so that the system is inherently stable (coherence) even when undergoing dynamic, internal change; it does not fly apart while self-organizing |
| **self-determined structure:** as the complex system adapts to maintain its viability (i.e., self-organizes), it can change its own structure; in other words, it learns as it evolves. This new structure has its own characteristics that set it apart from the original elements from which it emerged |
| **far-from equilibrium:** complex systems do not try to maintain balance and stability; equilibrium is temporary. Instead, they respect and manage the tension that arises as things change and emerge – instead of tension pushing things apart, tension holds things together so something new can be created |

classroom arrangements, patterns, behaviours and knowledge can emerge to move the learning forward, always in formation and co-evolving. System stability and systemwide change are equally accommodated.

Learners and teachers would intellectually bounce off each other knowing that equilibrium is not the goal but rather dynamic co-evolution. All systems are embedded in their environment, and when one changes so does the other – they coevolve (Fryer, ca. 2001). In this process, tensions and chaos are expected, respected and managed, because they lead to powerful, deep learning. The shifting nature of the ever-evolving learning environment cannot be attributed to any one person but arises due to dynamic and spontaneous interactions among actors in close proximity. Indeed, any new arrangement creates new possibilities, patterns and laws, but these “cannot be anticipated even with the most intimate knowledge of the components or agents” (Davis & Sumara, 2010, p. 857) from which the new entity arose. Small, local, leveraged actions lead to systemwide change.

And – the classroom does not fall apart as it is self-reorganizing, because tensions ironically (paradoxically) hold things together as learning transforms into something new (Senge, 2006). In more detail, interactions at the interface of things can become tense (stretched, rigid and unyielding). Emergent and healthy tensions, however, hold things together so something can emerge. These tensions provide order in the chaos, because it is assumed that people are capable of redistributing and diluting stress on the system. A textile science example illustrates this principle. The detergent bonds with the dirt and suspends it in the water to go out with the rinse. The tension holds things together as cleanliness emerges. In a classroom situation (like the dirty clothes example), “learning can be stable yet have constant flows of energy (causing points of instability). At these points of instability in learning, new structures and forms of order can emerge; that is, new learning can occur” (McGregor, 2013, p. 3573).

Indeed, within the world of complexity, learning refers to the ongoing, continuous process of transformations of both the knower and the knowledge as they interact (Davis & Sumara, 2006, 2010). Recognizing that complexity represents a profound challenge to educational philosophy and practice (Kuhn, 2009; Mason, 2008), Davis and Sumara (2006) offered it as an *attitude* for educators. An attitude is a positive or negative disposition (i.e., natural inclination or tendency) toward something like smoking, or drinking and driving. Gaining a complexity attitude requires educators to examine their own assumptions, educational philosophy, theoretical commitments, pedagogical leanings and paradigmatic positions. Holding a positive attitude toward complexity would mean educators would be interested in learning how it can shape their pedagogy (David & Sumara, 2006).

## 3. Pedagogy Defined

Pedagogy is Latin *pais*, "child" and *agōgos*, "to lead, draw forth or draw out" (Harper, 2020); that is, to lead or draw children forth to teach them. In contemporary times, pedagogy is "the art and science (any maybe even craft) of teaching [especially] the process of accompanying learners; caring for and about them; and bringing learning to life" (Smith, 2019, p. 3). With this definition, Smith (2019) distinguished between (a) teachers (the craft and science/theory of giving instruction in content and subject matter in schools) and (b) pedagogues (the art and intuitive aspects of giving philosophical and moral guidance for learners' lives). In the process of helping students meet learning outcomes, pedagogues also help them flourish by focusing on their well-being and happiness (Smith, 2019).

If educators were to embrace a holistic approach, they would draw on a combination of the science, craft and art of teaching, so they can ensure that learning engages, respectively, the head, hand and heart (spirit) – "the whole person" (Smith, 2019, p. 9). To summarize, a good teacher and pedagogue will (a) accompany learners (journey alongside them); (b) care for and about them; and (c) bring their learning to life with the latter including *teachable moments* where students deeply internalize some lesson, augment their knowledge base and change their life (Smith, 2019).

### 3.1 Teachable and learnable moments

Teachable moments can happen when least expected. These fleeting moments can be sensed, seized and interpreted to ensure deeper, richer learning. If handled appropriately, a teachable moment can become "a learnable moment" reflecting the confluence of factors emergent in the learning environment (Hyun & Marshall, 2003, p. 124). Such environments value the possibilities emergent from "the interweaving nature of learning" (Hyun & Marshall, 2003, p. 112). When the teacher is flexible enough to value learners' thinking, teachable moments become "an important pedagogical approach" (Hyun & Marshall, 2003, p. 112).

Of interest herein is the premise that "the 'teachable moment' may in fact be a case of emergence on the classroom level" (Davis & Sumara, 2006, p. 82). "Emergence...refers to the arising of novel and coherent structures, patterns, and properties during the process of self-organization in complex systems. Emergent phenomena are conceptualized as occurring on the macro level, in contrast to the micro-level components and processes out of which they arise" (Goldstein, 1999, p. 49). Gale (2006) agreed that embracing emergence enables teachable moments to be more than incidental; instead, they become an "integral part of a pedagogical commitment to student voice, social engagement, critical inquiry, and integrative learning” (p. 6).

In plain language, to reiterate, the CAS classroom can self-organize, adapt, co-evolve, re-form and change direction without the need of external force or guidance. The constant one-on-one engagement of learners with each other, teachers and emergent knowledge and insights represents the micro-level components whose interaction leads to macro-level classroom phenomenon (Goldstein, 1999).

With the right pedagogy, teachers can intentionally design a learning environment that fosters self-organization, wherein learners gain a deep education through powerful classroom dynamics. This approach *wants* teachable moments to become the norm, so learners can grasp intended and unexpected insight into what is being taught (Davis & Sumara, 2006; Davis, Sumara, & Luce-Kapler, 2008). This happens when people “invite the unexpected to interrupt and change the direction of classroom work” (Gallagher & Wessels, 2011, p. 239). Through intellectual gymnastics, learners may come to recognize, respect and learn about and from complexity (Davis et al., 2008; Davis & Sumara, 2006).

## 4. Deep Education

Complexity and deep education go hand in hand (Davis & Sumara, 2006). “Dealing with complexity necessitates constant re-creation and intellectual reconceptualizing” (Tochon, 2011, p. 30), which are hallmarks of deep education. Also, deep education “promotes a philosophy of curriculum that explains and addresses the current stakes” (p. 5) while “quest[ing] for a *deeper* sense of humanity and humanness” (Tochon, 2010, p. 3). With deep education, students learn to live responsibly with other humans and ecosystems as they experience complex life on the edge of chaos. They become comfortable with relentless change, risk and uncertainty trusting that something *will* emerge (Fullan, 2013; Fullan & Langworthy, 2013, 2014; Kuhn, 2009).

Deep education is predicated on the assumption that educators must “transform expectations of what students *should and can do* and give them practice at doing these things in the world” (Fullan & Langworthy, 2014, p. 35). With teachers acting as activators, facilitators, coaches and change agents, students would ‘learn how to learn’ – that is, they would master the learning process in addition to mutable content. Teachers would relentlessly activate “next-level learning,” meaning they would push learners one step forward, over and over again (Fullan & Langworthy, 2014, p. 17). Deeper and deeper they would go contributing to the accretion of knowledge.

Instilling complexity thinking and digging deeper helps learners discern similarities across diverse phenomena (instead of focusing on differences) thereby enabling them to make unique and meaningful intellectual, synergetic jumps and conceptual connections (Davis & Sumara, 2006). Selby (2007) referred to these as quantum leaps described as “sudden, highly significant (sometimes extreme) advances or breakthroughs in thinking and perception” (McGregor, 2020, p. 8).

Much like Smith’s (2019) acknowledgement that pedagogy entails care of and about learners, proponents of deep education would assume that teachers can care about learners as human beings and leverage the resultant powerful relationships to help them become “leaders of their own learning” (Fullan & Langworthy, 2014, p. 15). Once they take over their own learning, students would become deeply motivated with a purpose (pun intended). Deep education entices them to become “wholly submerged” (Fullan & Langworthy, 2014, p. 27) in the learning process, which helps them gain deep self-confidence, perseverance and proactive dispositions to engage with complexity and the real world (Fullan & Langworthy, 2014).

Crick (ca. 2015) tendered a collection of deep education principles that operate at three levels: (a) the school as a complex adaptive system (CAS), (b) the teacher as facilitator and coach and (c) the students who learn to ‘do inquiry well.’ These principles include (a) authenticity (i.e., learning is relevant and meaningful to students), (b) active engagement leading to meaningful classroom discourse and (c) knowledge mapping and construction that are then connected to the real world. To better understand the essence of deep education, the next section distinguishes among surface, shallow and deep learning.

### 4.1 Surface learning

Surface learning, the lowest level of learning (nominal depth), is predominately based on both awareness and information that is memorized for later recall. Little understanding or meaning making takes place with rote learning, and the memorized unrelated parts go unlinked (Bennet & Bennet, 2008; Ramsden, 1992). This “mile wide and inch deep approach” (Bennet & Bennet, 2008, p. 408) to learning disadvantages students, because it prevents them from being able to address complex problems that require them to go deeper to see patterns, draw on synergy and make connections.

Although this broad knowledge covers a wide range of topics, its breadth leads to a lack of detail and is too general in nature when it comes to understanding complexity. No conceptual connections occur thereby leaving disconnected, fragmented bits of information. With surface learning, students fail to appreciate that new material is intended to build on previous work. They passively and uncritically receive new information thereby making it difficult to internalize it and turn it into knowledge (Houghton, 2004; Tochon, 2010). When addressing a complex issue, they can only *scratch the surface* making few inroads. That said, surface knowledge is better than none at all and can be a natural step to deeper knowing (Bennet & Bennett, 2008).

### 4.2 Shallow learning

Shallow learning "is superficial [not thorough] and trivial (insignificant or marginal) and [students] come away without great understandings or perceptions of an issue" (McGregor, 2020, p. 7). When exposed to shallow learning, students cannot bring their intellect and serious thought to bear on an issue (Anderson, 2014), meaning their understanding of complex issues is limited (Willingham, 2009). Not surprisingly, shallow learning leads to shallow knowledge that is not connected to central concepts. Often, those concepts are trivialized or presented as nonproblematic (Wiki Users, 2019).

Shallow education addresses the manifest symptoms of an issue but neglects to address the deeper concerns – the latent, underlying cultural, political or ideological issues (Stibbe, 2004). Instead, learners come away with some information and some sense of what they were supposed to learn and understand (Bennet & Bennet, 2008). However, without depth, they are disadvantaged when it comes to conceptual and theoretical understandings that require linkages and mental and intellectual connections (LeCun et al., 2015). They are incapable of these insights, but they *can* problem solve simple and complicated problems that require lower-level abstractions and more formulaic, standardized responses (Bennet & Bennet, 2008). A recent study affirmed this assertion. Stella et al. (2019) reported that high school students structured their schematic frames of mathematics and physics using formulaic jargon but could not link mathematics and physics to the natural world for problem solving

### 4.3 Deep learning

Deep education and attendant deep learning are predicated on the construct of *depth* versus shallowness. Depth refers to complexity and profundity of thought (penetrating deeply), incredible intensity (concentration and passion) and comprehensiveness of study (Anderson, 2014). Deep learning also entails understanding and questioning basic principles, exploring things in great detail, and putting forward an argument while expecting resistance and push back. It involves self-reflection and examining one's beliefs and value system (Nicholls & Adolphus, 2003). Deep learning helps students draw meaning and gain life-related understandings from their educational experiences (Warburton, 2003). Through deep learning, students are taught the skills and dispositions to find and pursue their own visions; build relationships; flourish; and strengthen their human, social and decisional capital (Fullan & Langworthy, 2013).

Such deep learning depends on an *academic mindset* that eventually actualizes when students *believe* that engaging with others and digging deeper into relevant issues can help them change their intelligence (Briceño, 2013). Students learn to self-direct their own education using this academic mindset (Briggs, 2015). Applying this mind set begins with relatively simple ideas, concepts and constructs. As each is internalized and becomes new knowledge, learning transforms into deeper levels of abstraction until very complex ideas are internalized. By progressing through multiple processing of different layers of facts, insights and impressions, learners move to higher, *deeper* levels of abstraction and internalized knowledge (LeCun, Bengio, & Hinton, 2015).

This way, students would ultimately construct their *own* framework for understanding deep, complex issues instead of relying on others to interpret them (Nicholls & Adolphus, 2003). This self-reliance is possible because, over time, deep learning helps people uncover relationships, discover patterns and make connections that "become the unconscious bedrock of ... deep knowledge" (Bennet & Bennet, 2008, p. 409). But the mindset, mental acuity and tenacity necessary for deep learning is "never fully achieved, it is always in the making" (Tochon, 2010, p. 2). Students are continually learning how to (a) focus on and develop central arguments (i.e., reasons for a conclusion) and (b) understand central concepts that are key to addressing complex issues (Houghton, 2004; LeCun et al., 2015).

Deep learning happens in the midst of complexity and chaos (Fullan & Langworthy, 2013). Teachers and pedagogues must help students "find the seeds from which new patterns develop" (Fullan & Langworthy, 2013, p. 1), because, as noted, chaos is not a lack of order but order emerging, just not predictably. New patterns are embedded in the seeds of chaos, meaning chaos must be nurtured, because potentiality and emergence exist most strongly in the zone called the edge of chaos (Kuhn, 2009). Deep learning (which releases potential) requires deep education, which then engenders deep knowledge (McGregor, 2014). Paradoxically, with depth comes in*sight*, which is the capacity to gain accurate, intuitive and deep understandings (Anderson, 2014).

### 4.4 Connecting levels of learning with complexity

Bennet and Bennet (2008) linked the three levels of learning (surface, shallow and deep) respectively with the complexity of the situation: simple, complicated and complex. Surface, rote learning is good for simple systems (onefold) where it is sufficient to recall memorized information and fundamental understandings. Shallow learning is appropriate for complicated systems that depend on people being able to anticipate, explain and problem solve. In these instances, students are comfortable with both causality and intuitive experiences.

Complex systems, however, depend on deep learning, wherein people can create, intuit and make predictions. They are attuned to their lived experiences and can detect patterns, draw on synergy and gain insights. Deep teachings bring out the structure of the subject or the complexity of the issue. Teachers ensure that students confront misconceptions and any blinders blocking their learning. Any mistakes or seemingly wrong turns are used as stepping-off points for powerful, deeper learning (i.e., those teachable moments). Things are allowed, even encouraged, to emerge, so that potential can be actualized (Bennet & Bennett, 2008; Houghton, 2004; Kuhn, 2009). Potential is Latin *potentia*, "power" (Harper, 2020), intimating that deep learning releases learners' power to deal with complexity.

In addition to the complexity of the classroom itself, educators must remain cognizant of the fact that individual students are at different stages of cognitive development. Thus, any attempts to instill deep learning must accommodate students' readiness for taking on complexity and abstract, contextual knowing rather than shallow, concrete knowing (Coulbeau et al., 2008). Also, educators must not eliminate or ignore students' "intentions/anticipations/inferences from the process of learning [else they] turn learning into a simplistic ... act" (Doll, 2008, p. 29). The incorporation of non-linearity (i.e., complexity) into learning experiences "would open a space for the creative emergence of new ideas" (Doll, 2008, p. 29). The next section elaborates on the essence of an emergent pedagogy to ensure deep education leading to deep learning.

## 5. Emergent Pedagogy

An emergent pedagogy actively strives for deep learning to emerge (Gale, 2006). Emerge is Latin *emergere*, "to rise up; the process of coming forth" (Harper, 2020). It means gradually appearing or coming into existence (Anderson, 2014). In complexity theory, emergence pertains to the forces that disrupt things leading to adaptation and change (Davis & Sumara, 2006). Disruptions and interruptions in the flow of things create spaces for emergence where new knowledge can break through the surface and come into existence (Gallagher & Wessels, 2011) (see Figure 1).

Six aspects of an emergent pedagogy are now discussed (see Figure 2): swarm metaphor; bifurcated teachable-moment learning; synergistic, leveraged learning; unknowable, unpredictable learning; robust learning; and meaningful learning.

Figure 1. Emergence (used with permission Microsoft Clipart).

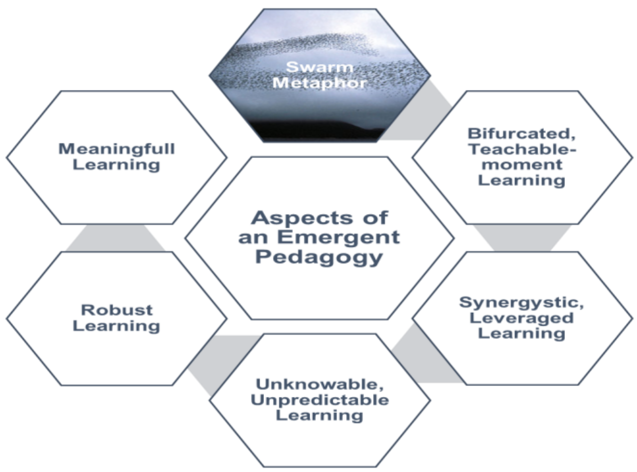


Figure 2. Aspects of an emergent pedagogy.

5.1 Swarm metaphor

To help people envision the dynamics of emergence and self-organization in a classroom, Dalke et al. (2007) used the swarm metaphor (see Figure 3). Swarms (a dense collection of self-propelled entities) behave as one with no central control (like a flock of birds or school of fish). They are non-equilibrium systems comprising self-directed organisms whose behaviour emerges as the collective moves as one. Their swarm (collective) intelligence reflects interacting locally with each other and with their environment (co-evolving). But, no one agent is in control, and most individual agents in the swarm are unaware of the global behaviour; *yet*, the swarm repeatedly reorganizes, moves and changes direction (O'Loan & Evans, 1999). This is a powerful classroom metaphor and visual image of a CAS classroom.

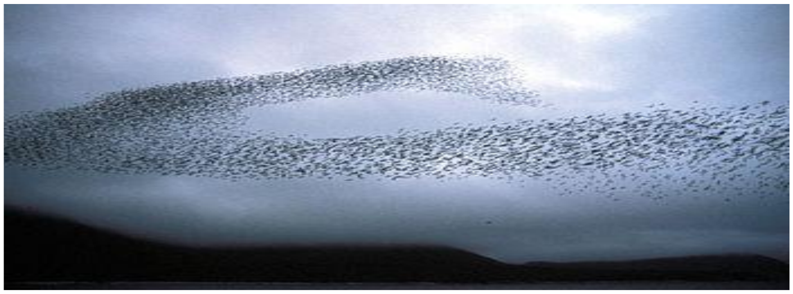

Figure 3. Swarm (used with permission Microsoft Clipart).

### 5.2 Bifurcation points

Emergent learning involves bifurcation (forking off or splitting in two). Ireland (2007) used concepts from chaos and complexity theory to create sustainability curricula that include bifurcation. She maintained that learning can be stable yet have a constant flow of energy that causes points of instability that disrupt learning. This is where new structures and forms of order of increasing complexity can emerge (perhaps those teachable moments). Things are happening in the classroom beneath the surface ready to come into existence. Small changes in a system can lead to sudden changes in its behaviour – emergence (breaching the surface). At these bifurcations, branching-off points, learners have extraordinary sensitivity to small changes in perceptions leading to unpredictable future paths of learning while trusting that learning *will* occur.

The lesson here is that teachers must be willing to accept unexpected disruptions and interruptions to learning (i.e., bifurcations) and take advantage of teachable moments to turn them into learnable moments (Burk, 2012; Dalke et al., 2017; Hyun & Marshall, 2003). The deeper students can go, the better they can grapple with complexity. And because pattern identification and change is the most important work that emergent educators can do (Dalke et al., 2017) (especially new mental patterns emerging), it is imperative that teachers assume that randomly generated patterns or learning paths are revisable, and things can continue to be re-imagined. Learning is thus unending, and what *is* learned is perpetually revised with new patterns, divergent paths, bifurcations, and connections always emerging. The bifurcation construct helps us explain what happens at the critical point when students transition from shallow to deep learning. When the parameters of their learning system change, the stability of their learning changes too – hopefully in the direction of deeper learning.

### 5.3 Synergistic, leveraged learning

In the true spirit of a CAS, teachers using an emergent pedagogy take advantage of instability and *leverage* learning (Burk, 2012; Mitra, 2012). The purpose of leverage is movement, which occurs when a lever (e.g., a pry bar) is strategically positioned so that the force (the effort) overcomes resistance (e.g., the heavy rock is moved) (Davidovits, 2008). Leveraging learning involves influencing it, so that it moves from shallow to deep enabling students to learn how to self-organize and self-direct when engaging with complexity (Senge, 2006). Unexpected learning outcomes can arise at higher levels because of lower-level individual decisions, which might seem unconnected but are actually synergistic, as they cooperate for an enhanced effect (Dalke, Cassidy, Grobstein, & Blank, 2007; Davis & Sumara, 2010). Leveraging these moments is key to an emergent pedagogy.

Leveraged learning operates on the principle that small knowledge of something helps with learning something additional and harder to learn. Initially, learning is slow and, some would say, on the surface. As more things are learned, however, learning different things becomes easier, and learning moves along. This gradual progression can “fuel an explosion of learning” (Mitchell & McMurray, 2009, p. 1503), because small beginnings and changes can lead to system-wide changes. Although leverage cannot create accelerated learning, it can “change both the shape and timing of the acceleration” (Mitchell & McMurray, 2009, p. 1503).

### 5.4 Unknowable, unpredictable learning

Not surprisingly, Ellsworth (1992) intuitively described an emergent pedagogy as teaching “practice grounded in the unknowable” (p. 115). Teachers employing an emergent pedagogy have come to recognize how impossible it is to know ahead of time what students will actually learn (Ellsworth, 2005). Instead, learning is “allowed to emerge sensitively and moment to moment” (Gallagher & Wessels, 2011, p. 241). Nicholson (2005) concurred, explaining that an emergent pedagogy creates “an encounter, rather than a meeting of fixed positions” (p. 46). An encounter is an unexpected meeting (Anderson, 2014).

From an aligned perspective, Dalke et al. (2007) believed that the human brain itself operates as an emergent system that cannot be controlled nor is it desirable to do so. Brains actively seek and process external information and, if lucky, turn it into internal knowing. “Understanding is itself an emergent process” (p. 115) rather than an end in itself. Understanding eventually comes into existence as a result of the interplay among three key aspects of the emergent learning process: cognition (analytical), experience, and reflection (intuitive). Understanding is an outcome of a person’s internal dialogue among these three aspects rather than just being dependent on one aspect – analytics (Dalke et al., 2007; National Research Council, 2012).

An emergent pedagogy also views learning as an emergent phenomenon, which refers to the arising of novel and coherent structures, patterns and properties during the process of self-organizing (i.e., rearranging things in response to disruptions and change). This perspective contrasts with teachers forcing patterns and structures onto students and expecting them to accept them. In a CAS classroom, learning spaces are not deliberately structured. Instead, they are open and organic, so that learning becomes focused on moving out into the world. Learning spaces continuously self-organize (reorganize, reform and adapt) into both networks and communities of meaning that are characterized by resiliency and further complexity (Burk, 2012). The whole process is unknowable (chaotic), yet those involved *know* and *trust* that something will emerge – learning *will* happen.

Relations and interactions within the emergent learning environment are the crux of everything and contribute to a "somewhat unpredictable [learning] project" (Dalke et al., 2007, p. 111). This idea mirrors chaos as order emerging (i.e., new learning) just not predictably. Dalke et al. (2007) believed that the complex learning process cannot (should not) be controlled much like Ellsworth's (1992) premise that emergent learning is unknowable. By appreciating that emergence reflects "the generative capabilities" of an educational system (i.e., its ability to produce something original), educators can let the learning process "lead to relevant, but to some extent, unknown outcomes" (Dalke et al., 2007, p. 115). A complex adaptive system like a classroom intrinsically deals with uncertainty and the unknown with everyone trusting the system to adapt to disruptions and interruptions, self-organize, change directions and co-evolve (Morin, 2008).

Paradoxically, during this process, personal autonomy (independent learning), interaction within an interdependent group, and system randomness are important in the establishment, functioning and evolution of ordered complexity in a CAS classroom (Dalke et al., 2007). They explained that teachers are unable to predict what these learning environments or systems will look like – they just have to let them play out – to emerge. Key to this terra incognita process is student exploration and attendant discovery with the expectation that simple, local interactions will morph into a substantial degree of self-organization at the system level (Dalke et al., 2007; Goldstein, 1998). Whatever learning and knowledge creation that does happen (emerges) would not have been possible with any other pedagogy.

### 5.5 Robust learning

An emergent pedagogy allows for robust forms of thinking and learning (Burk, 2012). Robust means strong, rich and uncompromised (Anderson, 2014). The essential question informing an emergent pedagogy is '*Are they thinking*?' instead of *'Do they know*?' (Mitra, 2012). To prompt robust thinking, teachers and students must pose *big* questions for which there are no immediate answers.

These big questions occupy students' minds; 'staying with' a question creates a space for self-organization and self-directed learning. Concurrently, schools would be viewed as both guilds (i.e., associations of people with similar interests) and regeneration hubs that bring new life to learning and make learning come alive (Burk, 2012).

Learning is considered robust if it (a) leads to long-term retention (months or years); (b) transfers to significantly different situations from where it was learned; and (c) accelerates future learning by which people learn quickly, effectively and deeply. Robust learning also leads to deeper conceptual understandings because of "better sense making [in a] learning event space" designed to ensure accurate and deep learning (LearnLab, 2008).

To ensure robust learning when employing an emergent pedagogy, teachers would abstract and summarize students' insights and then share those back with students, so the latter can build out from them again; learning is iterative and alive (co-evolution). Students would come to appreciate that new paths *will* emerge with nudges from the teacher, time and fellow-learner interactions (Burk, 2012; Dalke et al., 2017; Schultz Colby & Colby, 2008).

### 5.6 Meaningful learning

On a final note, an emergent pedagogy would ensure meaningful learning by edging learning beyond shallow and surface toward deep education. Meaningful learning would help students understand the deeper structure of problems and provide the academic mindset and tools to address them. This deeper understanding would entail learners storing information in an interconnected network within their brain as new knowledge. They would capture the deep structural features of the complexity of problems. In effect, not only would students learn about problems, but they would also learn the general principles and contexts underlying those problems thereby appreciating their interwoven nature – the complexity (Crick, ca. 2015; National Research Council, 2012).

In a meaningful CAS classroom, teachers would draw on instructional strategies aligned with emergence: experiential, inquiry-based, problem-based, thematic, integrated, issue-based, project-based, and student-centered, progressive learning. Teachers would be open to setting aside any planned lessons to make room for teachable moments and the exploration of tangential issues that arise. This way, learning can move (be leveraged) into unexpected and enriching arenas prompted by students' interests. Curricular content would be student relevant, authentic and contemporary (Briggs, 2015; Burk, 2012; Dalke et al., 2017; Hyun & Marshall, 2003).

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## 6. Summary and Conclusions

The red thread (line of reasoning) woven throughout this paper was that the educational system should embrace an emergent pedagogy, so that teachers can engage with deep education leading to deep learning. Shallow and surface learning are not enough. Students need deep knowledge and understandings, so they can deal with the complexity of their world. They need an academic mindset that encourages self-directed, flexible and responsive learning in classrooms conceived as complex adaptive systems that self-organize and co-evolve. To that end, contrary-to-the-norm constructs have to be learned and operationalized in the curriculum and the CAS classroom. These constructs arise from chaos and complexity theory and comprise the following ideas:

- complexity (multiple braided and interwoven strands),
- chaos (order emerging unpredictably)
- operating at the edge of chaos,
- emergence (gradually appearing or coming into existence),
- co-evolution (environment and learners reciprocally changing),
- tensions (holding things together),
- shifting and evolving patterns,
- leverage (movement despite resistance),
- resilience and flexibility,
- stability (coherence) in concert with nonequilibrium and, most important,
- self-organization (i.e., reforming, adapting and reorganizing in the face of disturbance and interruption *without* external control or leadership).

In a CAS classroom informed by an emergent, deep pedagogy, learning is unpredictable but fully anticipated. Teachable moments are welcomed and encouraged. Learning environments perpetually shift to accommodate what emerges within and among students. Continual transformations are the norm. Things can be stable and changing at the same time. What develops is interwoven and interdependent (complex), which is appropriate, because complexity is needed to address complex problems.

Teachers become coaches, activators and facilitators. Students take part in learning encounters and become self-directed change agents and responsible human beings who are able to network and connect with others and complexity. An emergent pedagogy ensures that emergence is intentional. With emergence comes potential – realized potential (power) can overwhelm complexity making room for stability within chaos. An emergent pedagogy is the lynchpin of the future. A responsible and accountable response to the world’s complexity hinges on this pedagogical and curricular innovation.

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