Abrahamson, D. (Chair & Organizer). (2018, June). *A complex-dynamical-system's view on the situated emergence of coordinated activity: From single cells to human collectives*. Symposium presented at the annual meeting of the Jean Piaget Society, Amsterdam, May 31 – June 2.

A Complex-Dynamical-Systems View on the Situated Emergence of Coordinated Activity: From Single Cells to Human Collectives

Dor Abrahamson (Chair), University of California, Berkeley, USA

Abstract:

Our symposium will present four research projects all working from a complex-dynamical-systems perspectives on development and learning. The projects share a fundamental commitment to ecological-cum-epigenetic models of skill development as emergent in complex biological–material-environmental dynamical systems in flux. The session reaches from primitive organisms through to humans learning as individuals, in pairs, and in groups.

We begin with single-cell organisms. In "Lessons from non-living dissipative structures for learning and development," the authors write: "The diversity of biological systems capable of perception-action suggests that, rather than reflecting a particular biological specialization, perception-action has its origins in a general physical principle that biology has richly exploited. We propose that this general physical principle resides in the thermodynamics of dissipative structures, giving them a rudimentary end-directedness.… The implications for theories of learning and development will be discussed."

A phylogenetic leap forward takes us to, "How to design for embodied dynamic development toward proportional actions, perceptions and descriptions?," where the authors set off from this premise: "As design researchers of mathematical education, we are interested in how to promote students' embodied dynamic development toward culturally accepted mathematical practices…. In line with enactivism, we assume that knowing is doing and aim to implement environmental constraints that enable learners to self-organize relevant mathematical behavior flexibly…. The results showed a variety of doings not yet described in the literature [whose] occurrence changed nonlinearly."

And then there were two students. In "Vygotsky's psychological systems as complex dynamical systems: Theorizing multimodal data of student–tutor collaboration on an embodied mathematical task," the authors used dual-eye-tracking data to find that, "Synchrony and coordination between a tutor's perception and a student's action reveal the emergence of inter-subjective coupling between the tutor and student's respective perception–action systems. At a critical stage of embodied interaction, the tutor's multimodal cultural intervention is interlaced with the student's personal embodied activity through iterative open-ended attempts to re-orient the student's attention towards the cultural meaning."

Finally, in "Exploiting self-organization: Skills for 'emergence management' in complex interaction dynamics," the author opens with, "Micro-genetic studies of joint improvisers (e.g. dance, martial arts) suggest significant applicability of dynamic systems concepts, but also point to a question previously overlooked by DST: *coupling based expert skills for dealing with evolving interpersonal dynamics*." The author argues that "interaction research should incorporate insights of enactive cognitive science (participatory sense making, non-serial processing, cascades of active sensing "directives" and co-evolving goals)..."

A Complex-Dynamical-Systems View on the Situated Emergence of Coordinated Activity: From Single Cells to Human Collectives

Dor Abrahamson (Chair), University of California, Berkeley, USA

Overview

Our symposium will present four research projects all working from complex-dynamical-systems perspectives on development and learning. Although it may not be immediately obvious, due to historical compartmentalization of disciplines, each with its own legacy, jargon, and methodology, our core theoretical views have much in common regarding the situated emergence of adaptive skill and the roles of artifacts and cultural agents in the process. Notwithstanding, each paper brings a unique view on the subject, with each view in turn contributing to a deeper understanding of the process. These views bear implications both for the theory learning and for instructional practice. It is through this symposium that the researchers' common grounds would be surfaced even as their differences could be articulated and perhaps negotiated into mutual coherence. That would be a fine outcome moving forward, as we seek to build greater cohesion across scientific views on diverse phenomena involving the collective and self-regulating emergent evolution of sensorimotor and conceptual activity.

1. Lessons from non-living dissipative structures for learning and development

James A. Dixon[1,2], Benjamin De Bari[1,2], Dilip Kondepudi[1,3], Bruce Kay[1]

[1]Center for the Ecological Study of Perception & Action
[2]Department of Psychological Sciences, University of Connecticut
[3]Department of Chemistry, Wake Forest University

All organisms develop the ability to perceive and act in the service of ends and goals, no matter how rudimentary. Behavioral scientists have traditionally considered perception and action as properties of higher-order animals, but recent work shows that all living things, including single-celled organisms, plants, and fungi, develop the ability to detect information in their environments and use that information to guide action. The diversity of biological systems capable of perception-action suggests that, rather than reflecting a particular biological specialization, perception-action has its origins in a general physical principle that biology has richly exploited. We propose that this general physical principle resides in the thermodynamics of dissipative structures, giving them a rudimentary end-directedness. Dissipative structures famously demonstrate the emergence of morphology from flows of energy and matter. The class of dissipative structures includes a variety of familiar phenomena (e.g., tornadoes, fluid convection), but also contains the entire set of biological organisms. In this talk, I will present evidence in support of the hypothesis that elementary perception-action capabilities develop from the thermodynamics of dissipative structures, given the appropriate physical constraints. Using both electrostatic and chemical dissipative structures, we show that dissipative structures can: (a) detect and move to regions that have greater available energy; (b) move against a predominant gradient in order to obtain better energetic resources; and (c) learn to behave in ways that increase the flow of energy through them. The implications for theories of learning and development will be discussed.

2. How to design for embodied dynamic development toward proportional actions, perceptions and descriptions?

Rosa Alberto[1], Shakila Shayan[2], Marieke van der Schaaf[2], Arthur Bakker[1], Dor Abrahamson[3]
[1] Utrecht University, Faculty of Science (Freudenthal Institute)
[2] Utrecht University, Faculty of Social and Behavioral Sciences
[3] University of California, Berkeley

As design researchers of mathematical education, we are interested in how to promote students' embodied dynamic development toward culturally accepted mathematical practices, in our case proportionality. In line with enactivism, we assume that knowing is doing and aim to implement environmental constraints that enable learners to self-organize relevant mathematical behavior flexibly. But what are learners' mathematical behaviors, how do these self-organize, and can this be altered effectively by task constraints? In order to answer these questions for learning proportionality we developed an embodied (tablet) task with different bodily and environmental constraints. Learners were asked in Piagetian task-based clinical interviews to "crack the code": keep an object green by moving your fingers along x- and γ- axes. The object became green when the relative position of the fingers was $= \gamma = \frac{1}{2}x$. They were instructed to either: (1) move the fingers along parallel axes (↕↕) or orthogonal axes (↕↔); and (2) keep green two bars, a full-screen or a scaling rectangle. For a subset of learners, we repeatedly observed, marked, and named the real-time unfolding of their mathematical behaviors -- actions (moves), perceptions (gaze), and descriptions (think-out-loud) -- and focused on changes within and across learners and tasks. The results showed a variety of doings not yet described in the literature. The occurrence of behaviors changed nonlinearly: certain (combinations of) actions, perceptions and descriptions became more or less prominent, largely in a self-organizing (deterministic) way, characterized by different time-scales and degrees of stability. Some doings occurred uniquely in/with bodily and environmental constraints and could be interpreted as different facets of the mathematical practice of proportionality. We will discuss the implications of our findings for future designs of environmental constraints to further promote mathematical dynamics.

3. Vygotsky's psychological systems as complex dynamical systems: Theorizing multimodal data of student–tutor collaboration on an embodied mathematical task

Anna Shvarts[1], Dor Abrahamson[2]
[1] Lomonosov Moscow State University, [2] University of California, Berkeley

This proposal draws theoretical parallels between Vygotsky's socially originated psychological systems and complexity theory of teaching–learning processes as self-organizing, adaptive dynamical systems in flux. The proposed approach to educational research subsumes and integrates enactivist and sociocultural perspectives on teaching–learning phenomena, providing new theoretical perspectives on the micro-ontogeny of mathematical concepts. When individuals engage in goal-oriented social enactment of cultural practice, such as performing mathematical tasks, they come forth into a self-organizing complex dynamical system of student–tutor interaction. We investigate the nature and evolution of this collaborative system in the empirical context of a design research project, in which tutor–student dyads participated in a teaching–learning joint activity oriented on completing an interactive non-symbolic computer-based manipulation task. The data included dual eye-tracking (DUET)—computer reconstructions of the participants' synchronous dynamical gazes—as superimposed onto videography of the virtual objects being manipulated as well as contemporaneous vocalized and gestural utterance. These multimodal data occasioned opportunities for the analysts to witness and model the phenomenon of teaching-learning as the nuanced, incremental co-action of two independent sensorimotor systems co-attending to problem-solving physical actions in a shared perceptual display. In particular, we model these data as evidencing a student–tutor complex dynamical system gravitating towards normative practice whence cultural mathematical meaning emerge. Findings suggest the hitherto under-theorized participatory role of tutors' perceptual activity in supporting students' idiosyncratic sensorimotor engagement and promoting its cultural objectification. Synchrony and coordination between a tutor's perception and a student's action reveal the emergence of inter-subjective coupling between the tutor and student's respective perception–action systems. At a critical stage of embodied interaction, the tutor's multimodal cultural intervention is interlaced with the student's personal embodied activity through iterative open-ended attempts to re-orient the student's attention towards the cultural meaning. Theorizing the student and tutor as constituting a complex dynamical system in action enables us to characterize and explain empirical data that would have remained opaque through analyzing individual activities per se.

4. Exploiting self-organization: Skills for "emergence management" in complex interaction dynamics

Michael Kimmel
University of Vienna

Micro-genetic studies of joint improvisers (e.g. dance, martial arts) suggest significant applicability of dynamic systems concepts, but also point to a question previously overlooked by DST: *coupling based expert skills for dealing with evolving interpersonal dynamics*.

Improvising together merges joint generativity with interaction regulation, as agents must produce complementary and well-timed co-actions. To achieve this feat, improvisers must be consummately capable of reading, reacting to, and sculpting the coupling dynamics in real time, i.e. they co-modulate partner actions and create joint synergies, while tracking the state of the whole system. Furthermore, to stay abreast of biomechanic and interactive complexity, it takes adeptness at balancing multiple demands into "simplex" solutions; determining control parameters that the interaction system responds to; staying poised for the unknown (i.e. cultivating *metastability*); and constraining the body in basic ways to open desired systemic degrees of freedom elsewhere.

Seasoned experts skillfully embrace "emergence management" as they relate to a self-organizing dynamic larger than themselves. Instead of directly controlling or even anticipating, they continuously nudge, constrain, and enable the emergent process, while exploiting affordances opportunistically. In this real-time process, individual intentions are best understood as *constraints on dynamics*. They dynamically respond to and co-shape the interpersonal system, from slightly tweaking the ongoing dynamic to a decisive "no, but." As a benefit, the ongoing interplay of interactivity and intentions can become a generative principle in its own right. Through continuous cross-scaffolding, complex and creative joint actions can arise that no one envisaged as such, hence *distributed creativity*.

Good emergence management presupposes that agents *softly assemble* task solutions from an array of micro-resources. They first learn to control and vary parameters independently; later they mix them into balanced "blends" that respect trade-offs. Soft assembly continuously incorporates and, where possible, exploits the external dynamic. Moreover, its principles elegantly explain how embodied creativity arises, i.e. by combining dynamic primitives in novel ways.

In conclusion, I argue that interaction research should incorporate insights of enactive cognitive science (participatory sense making, non-serial processing, cascades of active sensing, "directives" and co-evolving goals), although radical anti-representationalism overshoots the mark.