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Editorial Introduction: Education is a Dynamical System

Dimitrios Stamovlasis[1]**,** *Aristotle University of Thessaloniki, Greece*, and **Matthijs Koopmans,** *Mercy College, Dobbs Ferry, NY.*

Welcome to this special issue of NDPLS on Nonlinear Dynamics in Education, which presents an overdue attempt to describe the advances in educational research from a Nonlinear Dynamical Systems (NDS) perspective. In other fields such as psychology, economics and the life sciences, NDS has already been highly influential (Koopmans, 2009). Education presents a field of inquiry where the considerable potential of this new paradigm has not yet been fully appreciated.

The emergence of NDS thinking constitutes a challenge to the dominant paradigm in educational research. It introduces a new way of thinking, a new epistemology and offers a new perspective on educational reality. Noticeably, in education, NDS, from its earliest times, has been better equipped than other paradigms to describe complex phenomena evolving in time (Lemke & Sabelli, 2008). Besides providing an alternative theory about educational processes, NDS also offers a set of on quantitative nonlinear statistical methods (Guastello & Gregson, 2011) that are uniquely tailored to the study of dynamical phenomena. And as a meta-theory, NDS inspires the development of new questions and hypotheses about education and its impact, as the papers in this issue clearly illustrate.

Traditional quantitative research methods tend to be oriented to the analysis of educational outcomes rather than dynamical processes, and ethnographic studies, while being concerned with those processes, typically do not utilize a NDS vocabulary when describing change. A growing inter-est in NDS within interdisciplinary perspectives is apparent in the literature, covering studies in a range of educational contexts. Studies on students' academic achievement (Guastello, 1987), learning trajectories (Steenbeek & van Geert, 2013), problem solving in science education (Stamovlasis, 2006, 2011), and nonlinear pedagogy on game play and movement skills (Chow, Davids, Button, Shuttleworth, Renshaw & Araujo, 2006) are some representative examples of this new paradigm. Important theoretical work has also been done in this area, for instance to examine the applicability of the NDS paradigm to teaching and learning (Ricca, 2012) and to curriculum development (Doll, 2012).

While significant in their own right, these developments also help to set the stage for an agenda of rigorous educational research from a dynamical perspective to inform theory, practice and policy. This special issue takes a step in that direction by presenting five state of the art papers, which investigate nonlinear phenomena, associated with educational processes at various levels

[1] Correspondence address: Dimitrios Stamovlasis, School of Philosophy and Education, Faculty of Philosophy, Aristotle University of Thessaloniki, 52124 Thessaloniki, Greece. E-mail: stadi@auth.gr

complexity; from the micro or individual case level to the macro level of the education system as a whole. Moreover methodological issues and related statistics are presented and analyzed in each paper accordingly.

The first contribution, Koopmans' paper, addresses the gap in our knowledge that results from the reliance on randomized control trial studies to establish cause and effect in education assuming simple linear input-output relationships. The author questions from an NDS perspective the elevation of this method to the gold standard, pointing out that an intervention is not a singular entity, but rather a process, that generates causality and deserves to be examined as such. Four principles that govern the self-organ-izing behavior of educational systems are highlighted: *recursive causality*, the distinction between *endogenous* and *exogenous* processes, *self-organized criticality* and *emergence*. The outlined perspective brings a new set of methodological necessities to the study of causal processes. Catastrophe theory and nonlinear time series, which seldom used in educational research, might be productively implemented to improve our understanding, while NDS concepts, tools and models can indicate the linkages between the behavior of the micro level/individuals and macro level/larger systems and how the feedback between those two systemic levels can maintain stability or produce changes within these systems.

In the second contribution, Pennings, Brekelmans, Wubbels, van der Want, Claessens and van Tartwijk analyze real-time teacher-student interactions using the method of State Space Grids (SSG). Informed by Interpersonal Theory, teachers' interpersonal profiles are characterized in terms of *agency* and *communion*, based on their behavior in the classroom. SSG is a NDS tool developed to map characteristics of real-time interpersonal teacher behavior, while measurements of the *content* (attractors) and *structure* of changing behavior (variability) are provided. The method could be seen as connecting aspects of teaching processes at the *micro level* (interpersonal behavior) with *the macro level* characteristics educational components (interpersonal profiles). Studying the dynamic interplay between these two levels of interactive behavior, the authors argue, has important implications for educational practice.

In the third contribution Tani, Corrêa, Basso, Benda, Ugrinowitsch and Choshi present a model for teaching motor skills. Within the general framework of NDS humans are considered as open systems being in con-stant interaction with their environment and functioning far from equilibrium. Thus, they are able to reach more complex state of organization as they acquire motor skills in the interaction with their environments. *Stability* and *adaptation* refer to two inherent properties of this process. In learning, the adaptive changes might occur by a shift mechanism or a bifurcation mechanism depending on the learner's motor repertory. The education process is to teach for adaptation and to provide learners with the capacity to continuously adapt the new content toward growing complexity. The pro-posed model is based on core ideas originating from NDS theory and leads to a series of constructive suggestions applied to teaching motor skills, valuable to trainers, coaches and instructors of athletes e.g. for Olympic Games or other professional activities.

Stamovlasis and Sideridis present an interdisciplinary study in educational psychology and physiology investigating nonlinear effects in students' arousal levels under achievement situation as a function of approach - avoidance motivation. Ought-approach and ought-avoidance as distinct latent

variables affect the behavior of students associated with changes in both academic and emotional outcomes. This paper employs catastrophe theory to model the arousal level (heart rates per minute) by the two dimensions of oughts as the control parameters: the ought-approach as the asymmetry and the ought-avoidance as the bifurcation factor. The proposed model has a better explanatory power than traditional linear models, explicating the role of ought-avoidance, a variable, which within the linear regime had an unexplained role. The essential contribution of this work is that it built bridges between NDS theory and educational psychology since the empirically supported bifurcation effects besides the articulate interpretation provides an important clue for a *self-organization process,* which characterizes the complex adaptive systems. Thus, *Self-Organization* is the fundamental theory underlying psychological and physiological processes, which can embrace the studies of phenomena in educational psychology and education.

Finally, Guevara, López, Posch,and Zúñiga contribute a study concerning the macro level, using a simulation model to improve our understanding of the causal processes driving the dynamic behavior of education systems as a whole. Using three state variables, general population, pupils population and school graduates in primary education (the case of Nicaragua), and also including nonlinear complex interactions between critical factors, e.g., the state of the economy, the state of the education system, and population literacy that affect the system's transition rates, the study demonstrates the final influence of these variables to the dynamics of schooling outcomes. The primary aim is to show that the model presented here, with all its assumptions about feedbacks and nonlinearities, can provide enough structure to adequately replicate the historical evolution of the education system under investigation. The nonlinear model suggests that *critical factors* embedded in feedbacks are responsible for a suboptimal level of progress and schooling outcomes and that this behavior, however, is not self-correcting, at least during the time horizon under investigation. This work exemplifies the nonlinear characteristics of the education system as a whole, emerging from their component interactions.

Few practitioners in the field (teachers, parents) would dispute that education is a dynamical system. It is therefore time for educational research to catch up with this basic idea. We hope that the papers presented in this issue effectively articulate this shift in our orientation toward the field, and set the stage for promising future work.

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