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Position paper

About the outdated Newtonian paradigm in education and complexity and a complexity science of learning: How far are we from a paradigm shift?

Comments on the position paper "Towards a new complexity science of learning and education" [Educ. Res. Rev. 2 (2007) 145–156]

Our call for comments on the Jörg et al. Paper on complexity science has led to the submission of many reactions from all over the world. Hoping to feed a real discussion on this important issue, we present the most solid reactions: Kumpulainen (Finland), Lovat (Australia), Alexander and Loyens (USA), Daly (UK), Pnevmatikos (Greece), Mayer (USA), Laevers and Heylen (Belgium), Leydesdorff (The Netherlands) and Human-Vögel (South Africa).

Jörg et al. will be invited to continue this valuable discussion.

F. Dochy, Editor

Unpacking the complexity of learning and education with a complexity paradigm?

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The paper co-authored by Jörg, David, and Nickmans (2008) in this issue reminds us about a very profound and critical challenge concerning learning and education in today's world. We can seriously ask: is education meeting the requirements posed by the present times on learners, social groups and the society as a whole? How about our theoretical and methodological approaches via which we approach and try to make sense of learning and education in diverse settings—what do they allow us to see?

Many critical voices have been expressed from different disciplines towards present-day formal education and its practices. Education is regarded as not meeting the complex reality of today's world; school structures and practices are seen as failing to adapt to the needs of increased diversities of populations and individuals that they serve. The continuous development and emergence of technological possibilities, that are presenting themselves with an accelerated pace in the social practices of everyday life undoubtedly challenge education even more. Technology and culture evolve so rapidly that it has become impossible to confidently predict the future and conditions for our existence.

As Jörg et al. (2008) in their paper argue, these are all great challenges for any educational system that historically have mostly been based on the premise that it is possible to anticipate what learners need in their future lives. As educational researchers, practitioners and policy-makers, we should be seriously concerned with how ill-prepared our educational institutions are in today's dynamic and even messy society characterized by growing diversity and ubiquity of communication and knowledge creation.

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In stressing the need for change in educational research and practice, Jörg et al. (2008) introduce a complexity paradigm that they argue to be better fitted to our rapidly evolving, dynamic times. For them, the complexity paradigm involves an abandonment of the desire to pre-determine outcomes when taking the complex reality into account. Education then should become possibility-oriented instead of ends-oriented (Jörg et al., 2008). The authors argue that many paradigms in the field of education are based on physicalism or linearity thinking and that these approaches do not take into account the complexity of educational reality and, therefore, fall short in developing an in-depth understanding of this reality. For them, the complexity paradigm is able to contribute to our understanding of the present-day dynamic reality making a difference to educational research and practice. Here, the focus is on the "transphenomenal" resulting in a transdisciplinary and interdiscursive approach of which orientation is geared towards self-organization and potentiality.

There are some questions and comments that can be raised towards the arguments and ideas proposed in the paper. I would like to discuss and challenge some of them here. After this, I would like to draw our attention to a bigger message this paper brings forward. That is to do with the possibilities of interdisciplinary and transdisciplinary research on learning and education.

1. Complexity paradigm vs. sociocultural and activity theory paradigms

If we understand the complexity paradigm as a new theory or approach to the science of education we can ask what is different in this approach compared to the existing ones? It becomes crystal clear from the paper that it is the recognition of the complexity of reality-including education—that is very much the core premise of the complexity paradigm. Is complexity paradigm a unique approach, one of a kind? Are we really currently living in a world of educational science whose paradigms are only based on a view of reality that is simple and ends-oriented? What about sociocultural and activity theory approaches to educational research and practice? What about ethnographic research that is currently being viewed as not only a research methodology but also as a theoretical paradigm (see, e.g. Green, Camilli, & Elmore, 2006). Complexity paradigm may be different from these other approaches. Yet, in what ways is it different and what difference does this difference make? Contrastive analyses of the complexity paradigm with other paradigms such as the ones listed above would be very helpful in order to grasp its potential power to inform educational research and practice.

2. Complexity paradigm informing educational practice?

In what ways can complexity paradigm inform educational practice? Is it offering a new conceptual frame or new frames how to view, support, assess and change learning and education in today's world? Does it aim towards reform efforts on a conceptual level or are there concrete, practical educational applications that can be generated from research rooted in the complexity paradigm?

Researchers of educational change, such as Sarason (1993) and Tyack and Cuban (1997) have argued that radical change efforts guided by top-down models in educational institutions have frequently proven problematic, producing disappointing results. It can be concluded from many of these studies that sustainable change in education requires multi-layered, multi-sited and temporally dispersed processes, simultaneously both incremental and radical (Engeström, 2007). This emerging view stemming from the activity theory and sociocultural paradigm, suggest that educational change happens in multiple, relatively small-scale steps that gradually become interwoven into a larger whole. Moreover, this view reminds that longitudinal changes in education are ultimately created by the participants themselves in their everyday practices of teaching and learning. This requires researching and understanding the dynamics of participation and non-participation as well as persistence and resignation within the learning community (e.g. conflicts, power struggles, identity work) involving educational practitioners and students (Hubbard, Mehan, & Stein, 2006).

Unfortunately, the paper of Jörg et al. (2008) does not describe comprehensively in what ways, when, under which conditions and conducted by whom does complexity paradigm contribute to educational reform efforts. Thus, it is hard to judge the potentiality and uniqueness of this paradigm for education and its change.

3. Interdisciplinary and transdisciplinary approaches to learning and education

The complexity of contemporary world has inspired more and more researchers and research groups in different parts of the world to begin to explore acute educational questions and challenges via interdisciplinary and/or transdisciplinary approaches. The complex questions and developmental needs of education are seen as requiring perspectives and wisdom not only from one discipline but from many. The paper of Jörg et al. (2008) also highlights the potentiality of transdisciplinary approach within the complexity paradigm. While drawing on the definitions of van Benthem (2002) and Jörg et al. (2008) characterize transdisciplinary research as such where the topic of research is approached and examined from several, different disciplines. Members of the transdisciplinary research team are adequately informed about other approaches via which the research topic is investigated to ensure productive collaboration and knowledge generation. Interdisciplinary research, on the other hand, involves examining a research topic from various angles and methods, eventually cutting across disciplines and forming new methods, concepts, and theories in order to develop a wholistic view and common understanding of the complex issue, question or problem at hand (Bruun, Huikkinen, Huutonieniemi, & Thompson-Klein, 2005).

In acknowledging not only the complex world in which we live but also the interdisciplinary nature of modern knowledge creation, it feels justified to suggest that educational research communities start to explore more the potentiality of inter- and transdisciplinary research and development work to advance educational science and practice. Questions, such as, *How to build a school for a future?* are likely to profit from interdisciplinary and transdisciplinary research collaboration. Here, experts representing the disciplines of educational science, technology, brain research, architecture and city planning, to mention but a few, harness their cultural knowledge and practices in order to solve a joint problem. This collaboration can also involve non-academic communities who join the collective problem-solving from their angle of visions. Although this collaboration may not always be easy, causing tensions and conflicts, it can be a powerful practice to go forward. At best, we can create new understandings about learning and education—both for educational research and practice.

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Response to
''Towards a new, complexity science of learning and education''

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I find myself in agreement with the notion that social science offers an inadequate set of considerations for application to pedagogy, that a new paradigm is needed, and furthermore that a complexity approach might work in eliciting the paradigm(s):

- Social science is indeed in crisis and might well have been from the beginning. By attaching itself to the epistemology and method of the natural sciences, it inherited a regime of objectivity that forbade the investigator relying on evidence obtained from within. Habermas (1972, 1974) has made a penetrating case for the fact that social science that relies entirely on 'empirical-analytic' ways of knowing produces constrained knowing for human action. Without knowing of the 'communicative' and especially 'self-reflective' ways, knowing is blind because the knower does not know the knower. The result may well be the erection of false structures for human action that, while consistent with the evidence of the empirical-analytic, are nonetheless devoid of what is required for humans whose lives are characterized by freedom to conform or not to such formal consistencies. In short, social science requires an epistemology and method that is imbued with self-knowing because its entire reason for being lies in the self-reflectivity implied in people studying people.
- The forbidding of self-reflective investigation led social science away from many of the disciplinary areas and methods that might have made it most useful to contemporary concerns. As an example, in a day and age that sees so much of the human community's future depending on resolution around religious difference, social science is sadly lacking the language and understanding to so much as engage with the debate, much less help with the resolution. Having been formed in an environment that considered the discourse of theology to rely on forms of evidence that it discredited, social science simply walked away to try and impose on humanity its own preferred discourses and its own privileged methods. The result is seen in a world struggling to understand and deal with the emergence of fundamentalist and radical theologies, the latter especially within Islam, with far less involvement from Western scholarship in the social sciences than might be the case.

- The aforesaid is simply one illustration of why it is that social science was bound to fail education in its quest for effective pedagogy, just as Dewey (1904) predicted many years ago. As above, the missing elements are in the 'communicative' and 'self-reflectivity' knowing spoken of by Habermas. Without communicative knowing, pedagogical theory will be formed around the standardized research findings of the cognitivists, behaviourists, enculturationists, poststructuralists, or the like, rather than being tailored to the needs of individuals as they are communicated to the pedagogue. Without self-reflectivity, the pedagogue will construct a learning environment that places her or himself at the driving centre of the learning process rather than as a participant who establishes environments through which all will learn, pedagogue and student, and in which the relationship between the participants, rather than the content and strategies, will be seen as most essential to the learning process (Bryk & Schneider, 2002).
- A social science approach to forming pedagogical theory cannot cope with the wider ways in which the service professions are being called to social agency (Carnegie, 1996; Hugman, 2005), rather than instrumental practitionership. Be it in education or social work, the traditional notion of instrumental service is being challenged by calls for schools and welfare agencies to take up a wider role for society in trying to reconstruct new regimes of learning and care, rather than simply repairing older functional regimes. In education, Carnegie effectively questioned the assumptions and intentions behind the clearly inadequate pedagogical practice of the day and set new goals for teachers to engage in wider forms of learning requiring new and bolder pedagogies. These forms of learning would encompass communicative capacity, empathic character, self-knowing, self-management and self-reflectivity, as well as intellectual development. Carnegie's call led to an array of work around quality teaching, including work that uncovered the 'pedagogical dynamics' needed for such wider forms of learning (Newmann & Associates, 1996). Among them were values-laden dynamics such as 'school coherence' and 'classroom ambience' that lay beyond the empirical-analytic domains of assessment and measurement that tend to dominate in regimes where social science assumptions are determinative. In turn, this has led to a spate of work that has shown almost beyond doubt that it is the values-laden nature of both the environment and the content of learning that has most influence in students doing well, including but not exclusively in academic terms (Benninga, 2006; Carr, 2006; Deakin Crick et al., 2004, 2005; Deakin Crick & Joldersma, 2007; Deakin Crick & Wilson, 2005; Lovat & Toomey, 2007). Among all the items that determine this values-laden nature, the role of the teacher and the relationship of that teacher with the learners is the most vital element of all (Bryk & Schneider, 2002; Carr, 2005; Darling-Hammond & Young, 2002; Rowe, 2004).
- In a word, I recognize the crisis of education and specifically teacher education that struggle to find new paradigms of practice and training that match the nature of the findings above. I agree that a complexity approach would be preferable to the dogmatics of a social science approach in eliciting the paradigm shift required. I agree also that the likes of Bandura and Varela are useful ways in which we might begin to expound a complexity approach and would suggest that a close reading of Habermas, and indeed Deleuze and Flyvberg, together with the findings around quality teaching and values education outlined above, might propel us well into this task.

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Complexity science: Path to educational enlightenment?

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Abstract

In this commentary, we weigh the assumptions and arguments forwarded by Jörg, Davis, and Nickmans (2007) and determine whether we are willing and able to follow the path they envision for a new era of educational research and practice. Although we also seek the ideal state of educational research and practice that the authors portray, and find much appealing about complexity science as a realm of exploration, we regrettably encountered formidable barriers on the path Jörg et al. laid out in their opening article. Herein we discuss those barriers that make it impossible for us to accept complexity science as the chosen path toward educational enlightenment that the authors envisioned.

1. Complexity science: Path to educational enlightenment?

From the opening paragraphs of their article, "Towards a new complexity science of learning and education," it is apparent that Jörg, Davis, and Nickmans (2007) are passionate about their desires to transform the current state of educational research and practice. It is equally apparent that the authors are ardent believers that complexity science is the means by which this transformation of human learning and teaching could finally be realized. As with these authors, we hold that the state of educational research and practice is far from ideal and in need of serious reformation, if not transformation. However, years of failed reforms, pedagogical panaceas, and unrealized promises have caused us to become somewhat jaded and rather sceptical of the various roads to revolutions offered by well-intentioned educators (Alexander, 2006). Yet, as learning theorists and educational researchers, we remain open to new revelations that might truly bring about the deeper understanding of human learning and development we crave. Thus, the question for us was whether we could overcome our initial cynicism and scepticism and accept complexity science as the path we and others in the community of practice should follow in our quest for that ideal educational state.

2. Crisis mentality

Sadly, as we began to ponder the particular assumptions and arguments framed by Jörg et al. (2007) we found it increasingly difficult to stay the course theoretically. For instance, even before we could explore the authors' premise that complexity science is the hoped—for catalyst for pedagogical transformation, we were required to profess our belief in the crises facing educational research and practice. Specifically, as the authors wrote:

> 'To overcome this crisis in education, a first necessary step is to acknowledge the crisis and to recognize that an adequate theory of learning and education should take the complexity of reality into account.' (p. 145)

Why is it necessary to attest to this claim of a crisis? Is it not enough to argue that the understanding of and promotion of human learning is less than optimal or in need of improvement? What is gained by a heightened state of alarm? To the contrary, it would appear that one should be free to consider the merits of complexity science regardless of the level of need that is perceived. If, in fact, complexity science constitutes a more valid approach to the study of human learning and development, it would be valid whether we face a profound crisis or simply a less-than-ideal condition.

3. Broad claims

Further, we were subsequently called upon to accept on faith rather broad and significant claims about human learning and teaching that came without adequate substantiation. For instance, the authors argued that we need to set aside beliefs that there is anything simple about human learning or teaching. Yet, who within the contemporary educational community, their theoretical or methodological orientations aside, would proclaim that learning, development, or teaching are simple processes or constructs? Alternatively, our intimate knowledge of the literature would suggest that most educational researchers and practitioners perceive these phenomena as complex, complicated, dynamic, and multidimensional. The prominence of sociocultural, situated, and socio-emotional models, for instance, would serve as evidence that the complexity of human learning and teaching has long been accepted. What we have to appreciate about self-organizing systems, including educational systems, is that they do not simply discard aspects of the past in favour of something completely new or revolutionary. Rather, those aspects integrate and combine in new and evolving ways. Thus, if you accept the underlying premise of a complex adaptive system, "traditional" does not automatically mean inferior or weak; any more than "new" means superior or stronger, given that all things are in continual flux.

4. Construct confusion

In addition, as we progressed in our analysis, we encountered seemingly contradictory or misleading markers that made us doubt the utility of the authors' representations. For example, there are entire literatures that have established the distinctions between such central constructs as learning, development, education, schooling, and teaching. However, throughout the Jörg et al. (2007) article, these basic notions are problematically applied. Take the following quote from the article as a case in point.

> 'In this section, we take a look at the nature of educational research, and the possibility of a new science to improve pedagogical practice. . . [Educational practice] seems in a state of what Nicolaus Cusanus long ago has described as a state of 'learned ignorance' . . . remaining blind for what learning may be, unable to recognize its complexity.' (p. 146)

So, what is Jörg et al. (2007) proposing within the pages of this article? Are they forwarding complexity science as a theory of human learning; an approach to educational research; a model for pedagogical practice; or some combination thereof? It has proved sufficiently daunting to conceptualize the nature of human learning and the role that education, be it formal or informal, plays in that learning. It does not serve the authors' mission to speak about learning, education, teaching, and the like in the same breath without more linguistic precision or careful attribution.

5. Conceptual proliferation

It was not just these formidable barriers and obstacles that led us to abandon complexity science as the true path to educational enlightenment. Other conditions frustrated this intellectual track into complexity science. Specifically, as we progressed in our reading of Jörg et al.'s (2007) article, we quickly found that the path was obscured by a proliferation of complicated terminology. This proliferation made it hard to navigate the authors' message and appreciate the merits of their ideas. It was the Jörg et al.'s (2007) contention that the educational research community needs to become familiar with the lexicon associated with this nascent field of complexity science. This may well be true, at a theoretical level. Yet, inundating readers with these terms, while also introducing them to the premises and principles of a new theoretical model, only adds undue complexity to an already complicated topic.

6. The case for simplicity

The latter point regarding the inundation of terminology within the Jörg et al. (2007) article brings us to our closing issue. Complexity of a system need not translate into complexity in research design. In fact, the more complex the system under study, the more valuable it may be to focus on relatively simple, but integrated, patterns that can be discerned and tracked through untold iterations and transmutations. Well before complex adaptive systems theory was popularized, models and theories of human learning and of teaching had already evolved well beyond our ability to study them in their entirety. It is not solely our theoretical models that require updating. Even well-constructed educational measures within the literature only sample complex constructs; even sophisticated statistical procedures only deal with some limited sets of variables; and, even well-conceived and well-executed interventions only address select processes or specific individual or group factors. There is also a beauty or elegance that comes with simplicity that merits our appreciation. Consequently, no matter how complex our vision of human learning becomes, we are still well served by research studies and pedagogical practices that afford a clear, if simple, view of the educational terrain.

7. Final thoughts

We applaud Jörg et al.'s (2007) efforts to put the community of practice on a path toward educational enlightenment via complexity science. Yet, we have chosen to remain in more familiar and less unexplored terrain—at least for the time being.

As with the authors, however, we remain committed to and passionate in our quest to enhance current understandings of human learning and to improve the educational experience for all students.

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Comment on:
''Towards a new complexity science of learning and education''

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It is an absorbing contribution to a contemporary debate which has deep historical roots. I would have welcomed the authors' attempt to link their contribution, for example, to the earlier work on learning of Sfard (1998), a leading mathematics educator. Arising from her reflections on a special issue of *Educational Researcher* (Vol. 25, No. 4) she wrote about 'metaphors for learning' guiding the work of students, teachers and researchers. She argued for the appropriateness of grasping the salience of two apparently different 'metaphors for learning', considered as conceptual frameworks; what she termed an 'acquisition metaphor' and a 'participation metaphor' and the dangers of settling for one. Considering these two basic metaphors Sfard (p. 10) remarked:

'*It now seems that we can live neither with or without either of them. . . . . it is essential that we try to live with both*.'

It is salutary to be reminded that our chances of arriving at a unified conceptualization of learning seem rather remote, if at all meaningful, a point noted also by Jörg et al.

The paper appears to be rooted in a Euro-American centred orientation which is open to criticism. For example, given the authors' attention to theorising practice I find no mention of a significant project dealing with theorising educational administration over the past fifteen years associated with Gabriele Lakomski at Melbourne University and her former colleague, Colin Evers, now at the University of Hong Kong (see Evers and Lakomski, 2001, for an overview of this research project). This work addresses many of the issues raised in the Jorg et al. paper.

The pioneering work of Robinson (1998), at the University of Auckland, on the centrality of methodological considerations to an adequate analysis of the research-practice gap also deserves the attention of Jörg et al. Drawing on contrasting models of mind described by Clark (1997) as 'mind as logic machine' and 'mind as controller of embodied action', Robinson (2002) theorises the link between organizational learning and organizational problem-solving in a manner which is also relevant to concerns mentioned in the Jörg et al. paper. The above studies reflect the influence of recent developments in cognitive science.

'The Jörg et al. paper touched on evolutionary considerations in this context but without sufficient discussion of a complex debate which is gaining renewed critical attention. Recent work in the field is discussed in Carlson and Levin (2007). At an AERA presidential symposium during last year's annual meeting in Chicago, work on 'educating the evolved mind', and particularly on the contribution of David Geary to this field, featured prominently. More attention by Jörg et al. to this debate is required'.

With respect, the paper by Jörg et al. provides a welcome opportunity for older social scientists to encourage some of their younger, more eager and impetuous colleagues to get out a bit more and broaden the range of their acquaintances for the benefit of us all.

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Comment on:
''Towards a new complexity science of learning and education''

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For Kuhn (1970), the Copernican revolution is an example of a case in which the crisis in the reigning Ptolemaic paradigm was almost the only reason for the paradigm change (pp. 75–76). In the wake of Kuhn's pioneering work, scientists feel inclined to raise the anomalies in their scientific domain to the level of crises in order to 'evangelize' their 'new truths' and the need for paradigm change; the better the description of the crisis in the domain, the more mature the conditions for paradigm change. This messianic characteristic of paradigm change sometimes induces scientists, when they reflect on their science, to consider the anomalies in their domain of interest to be sufficient conditions for paradigm change. However, anomaly is not in itself sufficient justification for paradigm change. The process of improving the fit between fact and theory is also part of normal science. Scientists who are working within a paradigm use recognition of an anomaly contrary to their expectations as an important precondition for discovery. Thus, an anomaly, which is a failure of expectations, represents merely another puzzle to be resolved through the construction of improved models. No one would dispute the authors' claim that we should recognize that education is in crisis and that we also need to recognize the causes of the crisis in order to start to resolve the anomalies or the crisis. First of all, however, we need to determine whether the problems in education do in fact constitute a crisis (in other words, whether we need to look for a new paradigm), or whether they merely constitute an anomaly (which would mean that we need to improve our educational model).

For the authors, the main problem in education is the asynchrony between technology and culture in our times and our inability to predict the competences that will define the literate or numerate citizen in a few decades hence. The underlying idea of the authors is the need for education to predict the competences required to meet the needs of future technology, and then to provide future citizens with those competences. However, this is a never-ending process, which should be taken into account by any paradigm that has this idea as a priority. Both the current and the proposed new paradigm consider that education has an obligation to keep pace with technological advances, to adapt scientific achievements to everyday teaching practices, and to prepare students to be operational users (or consumers) of future technologies. In other words, the new paradigm does not promote something totally new that could not be obtained by improving the current educational system.

A challenging revolutionary idea in this respect could be to make it the priority of education to define its own objectives by envisaging what would constitute the ideal well-rounded citizen of the future. Technology would be then called on to solve the problems that might prevent individuals from achieving their goals. This approach would constitute a shift of educational target from preparation of citizens to be fully competent users/consumers of future technologies, to equipping citizens with the competences to be well-rounded citizens. Thus, we could take the opposite view of the asynchrony between education and technology. In other words, the asynchrony in culture and technology would not constitute a crisis but rather an anomaly of any educational system. If we were to see a crisis in this asynchrony, it would be that education constantly lags behind technology. Thus, even if the current educational system is to be placed in a position to make frequent adaptations to keep pace with constant technological change, we would still need a new paradigm in education. And the new paradigm would have to emphasize that human well-being takes priority over technology (technology for humans, and not humans for technology).

In this connection, I would agree with the authors' that the complexity and non-linearity of the human nature should be taken seriously and that there is a need to "humanize science". A paradigm with human nature as its priority could not ignore the complexity of human beings. I would emphasize the complexity of human beings, in contrast to the linearity of the process by which we assemble our research evidence and subsequently construct educational programmes. I also agree with the authors that there is a need for a "generative science of education".

As a result of our educational experience, we are far removed from Watson's (1930) firm theoretical belief that we (educators) can take any 12 human infants and, by applying behavioural techniques, create any kind of person ("beggarman and thief") we desire. However, the adherence of current educational systems to predetermined ends confects the basic

behaviouristic idea regarding the power of education. Only recently, scholars in cognitive developmental psychology argued that developmental science is ripe "to move from a teleological to a dynamic, phase-sensitive conception of development" (Demetriou & Raftopoulos, 2004). Within this proposal, the end-states of a given characteristic that may be reached by young students are determined by what the majority of adults in a given society and at a particular time in history consider to be predominant. Current educational systems, however, attribute failure to achieve the predetermined outcomes solely to a lack of effort on the part of the individual or, in special cases, to the individual's maturational and/or operational deficits. Thus, they systematically ignore the influence of adult society on the students' learning outcomes. This is the result of the value we accord to the individual instead of to the group, or rather to the context at the specific time the individual is active. Elcana (2000) stressed that the belief in context-independent truth is itself a basic Enlightenment view. Moreover, the faith in individualism is another more dangerous consequence of the "Enlightenment fundamentalism" that the new paradigm should imperatively avoid. In this sense, the authors' claim regarding the abandonment of ends-oriented education is the state of the art of our science.

As an alternative to ends-oriented education, authors are starting to suggest possibility-oriented education. The idea, however, is largely intuitive. This claim predicated on the realization of the complexity of reality itself and on acknowledgement that learning and education are also both complex. I appreciate that such a proposal could explode our myths about what education is. However, the authors could have discussed the benefits of the proposed solution for students or for society, but they do not. Imagine a student in the current educational system who achieves 50% of the predetermined outcomes and the remaining 50% are not achieved for various reasons. Let us assume that some of those reasons are a consequence of failure to take account of complexity. Turning to the new educational paradigm, complexity has been taken seriously, and the outcomes have become possibility-oriented. Imagine now the same student within the new educational paradigm. What would be the benefits for this student or for society? Policy-makers, teachers and parents must be persuaded of the benefits of the new paradigm. Who could explain the benefits to this student to people who can evaluate education only on the basis of learning outcomes? The percentage of predetermined outcomes attained is the only (quantitative) criterion that people (even education experts) understand. "Enlightenment fundamentalism" is everywhere! We have to agree that we need new concepts, a new lexicon, not only for complexity but also for the new prevailing arrangements and new prevailing qualities within the new paradigm.

Personally, I am convinced of the value of the new paradigm. The argument that the new paradigm is more suited to human nature is enough for me. And I also trust in human nature. Moreover, I am convinced that if something is more human, in the long run only good can come of it. The improved quality of students' lives is reason enough for me, and possibly also for parents, who witness the pressure their children are under every day to produce outcomes at school. However, I am afraid that this argument would not satisfy policy-makers, markets or public opinion.

Finally, I would agree with the authors that there is a huge chasm between theory and practice in our educational system. Regardless of which theory of education is the dominant one, teachers face the complexity of learning in their day-to-day practice. Theories are constructed reductively on the basis of evidence from groups of individuals. However, teachers (especially in primary schools) do not teach groups but rather each individual student. The adaptation of theory to every single student is the task of teachers. It is the teacher who customizes the targets. The new paradigm cannot avoid assigning this role to teachers. Thus, the education of teachers should be at the core of any new paradigm. Any wind of change in education should start from the preparation of teachers to master the new circumstances. As existing beliefs resist change, especially in the case of a paradigm shift (Thagard, 1992), there is a risk that the forthcoming conceptual revolutions will lack impetus unless a special effort is made.

In summary, the paper by Jörg et al. is itself an example of creative thinking. The proposed new paradigm is a really challenging idea. The objective is academically worthy. However, the analysis they develop in support of the need for a paradigm shift needs further elaboration if it is to be convincing to all stakeholders. The main question to be answered is why do we need a change of paradigm in education? What is wanted is a wealth of results, convincingly presented, from the application of the new paradigm in education. The authors do not yet have these results. However, we are all convinced that the new paradigm is necessary, and we should work hard to this end.

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Putting the science back into educational science

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Jörg, Davis, and Nickmans (2007) boldly call for "building a new science of learning and education" (p. 6) that can link theory and practice; but, regrettably, they only offer unsupported and nebulous opinions about learning and education that fail to meet the minimal requirements of science. As a new science of education, this position paper violates three fundamental requirements of science.

(1) Violation 1: Using sweeping opinions without supporting empirical evidence. A hallmark of science is that arguments are based on empirical facts, rather than quotes from "experts." Sadly, this is not the tact taken in this position paper. The authors offer page after page of sweeping assertions: "We believe that a profound understanding of pedagogical reality is necessary. . ." (p. 1) "We argue that the field of learning and education is in crisis. . ." (p. 1) "The ongoing development and elaboration of technological possibilities. . . make the situation even worse" (p. 2). If you are expecting strong claims like these to be supported by empirical evidence, you are likely to be disappointed. At best, some of the sweeping assertions are followed by the names of experts, or even quotes from experts, as if name-dropping were a substitute for empirical facts.

(2) Violation 2: Using vague concepts without concrete referents. Another hallmark of science is that concepts actually mean something—they can be defined in a concrete way so that others can tell what they refer to. If you are expecting terms to be clearly defined as they are presented in the text, you will be disappointed by this position paper. For example, consider this sentence from the very first paragraph: "Characteristics of this complexivist frame are a focus on the transphenomenal resulting in a transdisciplinary and interdiscursive approach, an orientation towards self-organisation and potentiality instead of pre-specified ends and an incorporation of a theory of change" (p. 1). Sentences like this – which are typical of this position paper – are simply too vague to critique. What is the meaning of terms such as "complexivist frame," "transphenomenal," "interdiscursive approach," "an orientation towards self-organization and potentiality," "pre-specified ends," and "incorporation of a theory of change"? Although some terms are never defined, several pages later, the reader is finally treated to a definition of transphenomenal: "how forms and events unfold and are unfolded in other forms and events, potentially in a nonlinear way" (p. 5). This definition – which also is typical – can best be characterized as incomprehensible.

(3) Violation 3: Presenting a nebulous theory that is incapable of generating testable predictions. If you adhere to the principle that scientific theories must be testable, then you will be hard pressed to see how complexity theory is a scientific theory. The heart of the position paper is that current theories of learning need to be replaced by complexity theory. What is complexity theory? On page 6, we learn that "complexity theory is not interdisciplinary, but transdisciplinary" but that description does not help us generate testable predictions. On page 5, we learn that "the complexivist question is . . . To which level(s) of complex emergence does a particular theory apply?" but it is not clear what data can be used to answer this question. The underlying premise of complexity theory is that "education is a complex system" (p. 5) but the description is so nebulous that I am unable to see how the theory could be tested empirically. Thus, with the way that complexity theory is presented in this paper we leave the realm of science – that is, testable theory – and enter a nebulous world of rambling opinion that is unlikely to advance our field.

In conclusion, I agree with the opinion that if we really want to improve educational practice, we need to understand how people learn (i.e., build a science of learning such as exemplified in Bransford, Brown, & Cocking's, 1999, How People Learn) and understand how to help people learn (i.e., build a science of instruction such as exemplified in Mayer's, 2008, Learning and Instruction). However, I disagree with the idea that this goal can be reached using unsupported assertions, vague concepts, and untestable theories. In my opinion – consistent with the consensus of educational researchers in Shavelson and Towne's (2002) Scientific Research in Education – the best way to build an educational science that can improve educational practice is to adhere to the tried and true methods of science – evidence-based arguments (i.e., basing conclusions on empirical evidence), clear definitions (i.e., defining concepts so they clearly refer to something), and testable theories (i.e., stating theories in ways that allow for testable predictions). If this position paper helps move our field towards a scientific approach to educational research – even as a reaction – it may well have served a useful purpose after all.

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How a new era for a science of learning and education has commenced

Reflections on the position paper "Towards a new, complexity science of learning and education"

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1. Executive summary

A theory can only be a theory for practice when it does not neglect the complexity of the educational reality and grasps the dynamics of the ongoing processes. This 'reality' is central and must be treated with respect. It should not be simplified in order to fit with the methodological tools of the researcher. An approach with multiple perspectives is more open to the complexity of reality and therefore is more likely to offer solutions for problems which arise in practice. This implies a shift in the attitudes of educational researchers towards a mindset dominated by two principles: (1) the principle of integration: any approach or statement which deviates from traditional approaches must be examined to enrich understanding; (2) the principle of modesty: there is no hierarchy to scientific approaches, every approach has its value. Scientists can only act according to this attitude by exploring the boundaries of their own paradigm and by becoming aware of the limitations of the ways in which they observe reality. The Piagetian concept of 'schema' helps us to distinguish the underlying process of how paradigms steer our observations of reality and it makes us aware of the necessity of collaborative approaches on an interdisciplinary and transdisciplinary level to obtain an accurate picture of the complexities of reality.

But there is reason for optimism. This plea for a new complexity in the science of learning and education is rooted in decades of initiatives within the field of educational research and practise. It deserves focused attention.

2. In the midst of a paradigm shift

For those who are aware of what happens at the global level in the field of social sciences, the position paper by Jörg, Davis and Nickmans will not only be welcomed but also read with excitement. In a vigorous manner it clearly expresses what can be found in many statements and keynote speeches at international conferences: scientific concepts and methods dominating the scene are under pressure and the reigning view on learning and teaching may be out of date (Pascal & Bertram, 2007; Vandenbroeck, 2007). Social sciences, the science of education and educational practice are in a stage of transition. The key message in the position paper offers solid ground to corroborate this observation and is, therefore, most refreshing. In fact, we have the privilege to be part of a new era taking shape. We are witnessing a process of change, new horizons appear, totally new views are beginning to dominate the scene: in short, we are in the midst of a paradigm shift.

Due to the many indications of this ongoing transformation, we hesitate to label this period as a crisis—a term used in the original position paper. A great many building blocks are already at our disposal enabling us to construct a new approach. Today, we are able to visualise what the science of education can and should be. There is already a lot to celebrate.

3. Science is about reality

Although it may be evident, one of the strengths of the position paper is that it puts reality in the middle—in fact: it is the ontological reality which comes before the version we 'construct'. Science deals with reality. Its mission is to explore and understand, to support sound actions based on a deeper understanding of phenomena and processes. A paradigm shift is being provoked by the experience that current approaches are not grasping the essence of reality. Previous paradigms do not deal with reality with the openness that allows the 'real thing' to 'be' and to enter into our 'system'. They do not pay due respect to the complexity of reality, in fact, they attempt to reduce it. In sum: they are missing the point.

At the same time, putting reality in the central position is courageous. It is an indication of the transition from a post-modern to a post–post-modern approach. In radical postmodernism the ontological reality has been denied. It felt as if there was no reality, but only very diverse and arbitrary constructions of it. Truth was a term to avoid, at the very least, to be negotiated

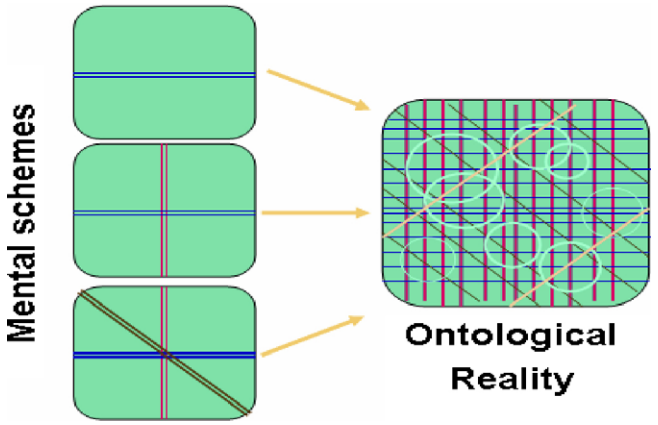
At the very least, the post-modernist discourse can be experienced as most challenging (Usher & Edwards, 1994). One examples of a challenge is its far reaching questioning, if not rejection of developmental psychology—one of the traditional fundaments of educational sciences. It certainly made us think a lot about the fact that the developments we observe are only possible stages as the result of specific contexts. Moreover, the idea that culture is created by interaction and that every new generation – including the youngest children – takes part in shaping that culture is a most thought provoking idea.

However, revisiting the notion of reality has benefited from the post-modern 'treatment' to which it has been subjected. It has rendered us much more open to complexity and supports the multiple perspectives we need in order to deal with reality in a proper manner.

4. 'Memes' and the concept of 'schema'

To understand the nature of paradigm shifts we must be aware of their fundamental nature. Whereas Harman (1970) refers to four components—perception, thought, valuing and action, Capra (1996) stresses the social and cultural dimension: a paradigm is shared by a group of people, it is a particular vision that defines a community. Paradigms represent the foundation of cognition. They function as the programme behind and above all programmes. One cannot escape ones' own paradigms. Even the questioning of a paradigm may be regarded as a beginning of change in the paradigm itself and therefore as the start of a paradigm shift. Moreover, paradigms do not change overnight. They cannot be adapted through simple deliberate actions or by having someone explain to you what the next 'view' might be. One does not choose one's paradigm, but, in a sense, one 'is' it and functions by it.

These characteristics of paradigms take us back to the Piagetian concept of 'schema' (Woolfolk, 1987). Schemas may be considered as 'spectacles' through which we are able to view reality. They determine what kind of reality we can construct when confronted with the 'ontological' realm. Schemas function like the programme (the software) which we use to process entering data.



A transformation at the level of the schema – a paradigm shift – is associated with the capacity to perceive more, to be able to utilize more dimensions. As it is illustrated in the graph above: the upper mental scheme only allows horizontal lines to be perceived while the lower one gives access to more dimensions of reality.

From the metaphor of the spectacles we can understand that the basic 'schemas' for psychosocial phenomena, including education, represent a structure that determines what we can experience and what is out of reach. When looking at developmental stages in young children, it is easy to see that in the growing capacity of the mind – 'die geistige Kraft' as Aebli (1963) puts it – the acquisition of object permanence is a milestone. In the 'Concerns Based Adoption Model' (Hall & Loucks, 1979; Hord, Rutherford, Hurling-Austin & Hall, 1987) – developed by Gene Hall and Susan Loucks-Horsely in the early 1970s and also used by Michael Fullan – we can see the progression from task-orientation (being focused on the 'how' question when implementing an innovation) to a pupil-orientation (being able to take the perspective of the learner while implementing the programme) as a clear example of this enrichment of schemas.

We believe that this concept of schema is associated with the notion of 'meme' mentioned in the position paper, as an attempt to grasp how theory works in relation to complex systems such as education. Further, we suggest making a distinction between basic schemas and theories: the first are situated at a deeper level.

5. The advancement of social sciences and the 'integration of paradigms'

A paradigm shift is a process at the level of cognition within the scientist. Scientific theories are rooted in the basic schemas that serve as the windows through which reality is observed and understood. Schemas lay the foundation for an

intuitive understanding; science is the articulation of these intuitions: theory and observation are mutually linked in a circular process.

In practice however, it is possible that theories, when disseminated, are only assimilated at the surface level without real development of the schemas that underpin them. That is why we can see how some 'behaviorists' reflect more empathy in their approach than some applicants of a 'client centred practice', for example. Theories are but the carriers of ideas. What we make of reality is situated at a deeper level.

The critical statements in the position paper – such as 'learned ignorance', 'blinding paradigms', 'learned incapacity to reflect', 'linearization of the processes', 'reduction', 'disciplinary pathologies'. . . – in fact refer to the limitations of the basic schemas, thus, the mental capacity of scientists in their endeavour to understand reality. But this observation focuses only on one end of the continuum. It is obvious that we deal with a diverse spectrum in which we can discern approaches and basic schemas that allow a wider and deeper articulation of properties of the observed reality. The position paper reflects a more advanced perception and a more refined observation of the field of education and social science.

Historically we can see that some scientists have been far ahead of others in developing a more complex construction of reality. At the global level, for example, we only now begin to see what was evident to Vygotsky almost a century ago. All of this makes us realise that paradigm shifts are the fruit of a long and slow process.

The direction in which we are heading begins to get clear. Putting reality at the centre implies that we have to view theories as servants and not as goals.

Every schema (or theory expressing it) that can shed light on reality and articulate aspects of it must be welcomed. This idea links perfectly well with the plea in the position paper for 'a new integrated set of paradigms'.

Such integration would in essence imply that scientists are capable of taking on board and assimilating the expertise developed within several approaches. It implies that they can handle dimensions elicited by behaviourism, psycho-analysis, Gestalt psychology, symbolic interactionism, the systemic view, the experiential approach (social) constructivism. . . Beyond the merging of approaches within one discipline (psychology and education), collaboration at an interdisciplinary level (including sciences) will constitute the next challenge.

All this contrasts with the actual situation where the forum is structured by a series of approaches entrenched in their own paradigms, producing their own journals and holding their own conferences.

6. Implications for scientists

The question is: how can we obtain a better, more gentle climate in which science is truly a refuge—a 'free' place', as it should be, where the exploration of new paths is encouraged along with the pursuit of research goals that, at first sight, seem crazy? This is a plea for diversity, a celebration of the complementarity in approaches—and a dramatic change with respect to the actual situation.

The position paper advocates a 'recognition of the crisis'—but we see this recognition in itself as a result of the (rising) new paradigm, not as the condition for the rise of it. This reflection is associated with the Piagetian concept of disequilibrium and the process of adaptation: the experience of conflict in itself already indicates that the schema is shifting.

If we can speak of a crisis, it is this constant tension in the scientific forum produced by the dominating positivist approach. The breakthrough of new paradigms with a more holistic approach, a recognition of circular processes and respect for the complexity of reality, will only be possible – as we have learned from history – when scientists develop themselves in order to constitute a majority that is able to question the dominant view, because that majority is able to "see more". Ruling out intuitive understanding (the avenue to complex realities) as part of scientific work, is limiting science to a kind of chessboard where cleverness and abstract logical thought rule.

Understanding reality begins with another 'perception' and, hence, with the development of more complex schemas. Without this development at a deeper cognitive level, we will either continue to have these dead end discussions or simply withdraw from any communication with colleagues who are 'on the other side'.

Such a development is only possible when scientists are educated in another manner: it is imperative to put the actual, 'physical' contact with the object of one's discipline at the centre of their training. This exposure to the complex situation – especially when dealing with sciences with a practical perspective – is of paramount importance. Learning to observe, development of the so-called 'clinical view' or phenomenological perception, is essential. This is where the 'basic image' of the arena one operates in as a researcher is formed.

The role of this developed 'basic image' is apparent when we deal with some quantitative methodologists. The problems do not lay in the methodologies: they are very sound and even the highly sophisticated and advanced statistical procedures can only be welcomed. Statistics help us to see patterns we cannot discern when dealing with individual cases. However, we are confronted with the tendency of a number of researchers to use statistics in isolation. To put it more clearly: it reflects the lack of imagination about the reality behind the figures.

In contrast to the precision associated with processing figures by SAS or whatever programme, crucial details are overlooked because one cannot envision the complexity of the field. Items in an existing questionnaire are altered without checking how respondents with different profiles interpret the questions. Observations are organised in ways that violate the 'ecological validity' (Brewer, 2000). As a consequence, research results are contaminated or contain artefacts. Statistical

procedures may be neat, but the collection of the data which one enters into the computer must receive the same attention and care as the statistical procedures.

7. Towards a new ethical code

To go back to our key question about how to create a new climate, we expect that in the long run scientists will achieve a more developed ethos in relationship to other approaches. This more productive attitude would be based on two principles:

(1) The principle of integration: "A different approach or statement must be analysed and understood to the point where it can be assimilated in one's own theory".
(2) The principle of modesty: "Whatever approach or theory that cannot be integrated in one's own view can never be rejected as irrelevant or foolish".

Both principles would create a more open atmosphere which is crucial for the 'advancement of science'.

The first principle would imply that one is capable of seeing the point made by another approach, that is: to see how and where it contributes to a better understanding and where it fails to make the multiple dimensions of reality visible.

The second would provide room for experimentation and creativity instead of blocking future developments.

We have learned from history how some views have too easily been rejected because of a lack of understanding. Copernicus and Galileo were not very popular when they changed the whole basis on which the theories of astronomers were built (Robinson, 2001). Old questions were not relevant anymore. However, by changing their views radically they got answers to many new questions.

Some concepts – for example in the theory of Rudolf Steiner – are beyond our actual capacity to grasp – and deserve the benefit of the doubt. That is: until we are able to fully understand his propositions we are unable to decide what kind of contribution they might make in unveiling reality.

8. The future is bright

It is time to resume the optimistic introduction to this paper. Why can we be positive about the actual status of educational sciences and hesitate to speak of a 'crisis'?

At the level of methodologies we can recognize a variety of approaches that fit very well in the frame of a 'new complexity in the science of learning and education'. Qualitative research methods (multiple case studies, action research, stimulated recall, biographical methods ...) have come to maturity. The use of vignettes, narrative approaches, the sharing of results with research subjects in order to take into account their perspectives, are becoming evident strategies.

Research is focusing more than ever on the process: that is, on what goes on within and between the actors—the teacher and the learner ... Thirty years ago this domain was seen as the 'black box'. The 'reconstruction' of the experience of the participants in education has now become a genuine part of research, one in which researchers go far in taking the perspective of the learner. That is why, for example, the variety of mental operations used by 5 years olds dealing with number can be identified. The notion of 'intuition', even in relation to the education of mathematics, is not taboo any more. In line with this the concept of 'cognitive load' (Hattie, 2003) is introduced to capture the developmental domains addressed in an activity.

At the level of educational concepts, new approaches are being developed worldwide—not just theoretically, but in interaction with practitioners. Under the umbrella of 'constructivism' the definition of a powerful learning environment has changed dramatically: we do not regard homogeneous grouping as the norm, but diversity comes into play as an asset. Cooperative learning is promoted and teaching is considered as a co-construction in which active participation of the learner is essential. The 'open framework approach', in which students and teachers engage in a circular process of exploration – both without refraining from initiatives – is the emerging model. Evaluation is taking new forms, with a higher level of participation by the learner (e.g. through peer-assessment and the introduction of portfolios, for example).

Just recently another concept has emerged which complements 'constructivism': "the notion of competence" which focuses on the outcome of the educational process. The concept serves equally well as a powerful key to the new paradigm for education. This vision entered the educational system from outside the field of education and began to take shape when society, and in particular corporate managers, expressed their discontent with regard to the output of education. Their key message: learning is not the point, rather, it is what one can do with what has been learned that has value. Competence is seen as a combination of skills, abilities and knowledge to perform in a specific task. This has consequences for education. The principle of competence-based learning implies that knowledge and skills should not be offered in isolation to learners. The concept of competence based learning entails combining three elements in learning: knowledge, skills and practice (Nedermeijer & Pilot, 2000). The concept of competence puts the educational system under pressure and rightfully demands an approach in which the complexity of competent behaviour is acknowledged.

The notion of competence-oriented education applies to a series of movements at the conceptual level. It goes against the (linear rational) practice of breaking educational objectives into pieces. Instead it is linked to a holistic approach as it tries to keep the essence of the educational objectives in mind. It therefore finds support in the theory of the multiple intelligence. The notion of competence forces us to see the so-called 'life skills' – such as self-organisation, creativity, social competence – as equal in importance as the traditional academic outcomes. It urges us to revisit Bloom's taxonomy and to see to it that activities offered do not only address the lower categories (such as reproduction), but always invite the learner to engage in problem-solving and evaluation. It impacts on evaluation by valuing so-called 'learning tests' as the preferred method of assessing competence: do not test what has been learned but how easily one can acquire new skills and understanding. It makes us aware of the many ways in which learning occurs and places the concept of 'implicit learning' at the forefront—captured as well by the notion of 'stealth education': many things that are learned outside or inside of the educational system remains unspotted by the teachers' 'radar'. It supports the distinction between superficial learning and deep-level-learning—i.e. the contrast between transformations at the level of the schemas or 'programme' as opposed to the endless insertion of new 'files'.

As can be expected from paradigm shifts, the impact is enormous. We already see – endorsed by the position paper – that the pillars on which the traditional model rests are affected.

It seemed so evident until now that teaching was about a process which started with the definition of objectives (remember: only technically correct if a verb was used in the statement) and ends with the final evaluation of the 'product'. Now we are convinced that – without loosing the essential, broader goals – we can create learning environments which bring to life the many possibilities in the learner and help us to engage in a joint journey leading to changes beyond our expectations.

9. Conclusion

Yes; these are exciting times! It is the merit of the position paper to open the gates and invite us to speak out about what seemed impossible to challenge until now. The topics of the 1970s and 1980s reappear—not in the same manner, but enriched with the enormous amount of scientific work accomplished during the last decades. The process of integration is inevitable, because reality rules. In view of the confrontation with that reality, schemas develop inevitably in one direction: they enable a better grasp on reality and a recognition that more dimensions exist than ever before.

At the same time we can hope that the social sciences, and particularly the educational sciences, engage in a process of emancipation. Recognizing that it is easier to prevent diseases through education than to develop the next sophisticated cure is our guide. Again the message is not one of polarisation – this time between the positive and social sciences – rather, it is a call for a growing investment in the social sciences – which are virtually totally dependent on state funding and are challenged with the complexities of the educational reality. Opportunities to engage in research and practice in the directions set out by the new paradigms must be provided. The future is bright.

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Complexity science and intentional systems

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In their position paper entitled "Towards a new, complexity science of learning and education," Jörg et al. (2007) argue that educational research is in crisis. In their opinion, the transdisciplinary and interdiscursive approach of complexity science with its orientation towards self-organization, emergence, and potentiality provides new modes of inquiry, a new lexicon and assessment practices that can be used to overcome the current crisis. In this contribution, I elaborate on how complexity science can further be developed for understanding the dynamics of intentions and the communication of meaning as these are central to the social-scientific enterprise.

Under the denominator of "complexity science" a number of physicists, biologists, and mathematicians have proposed "self-organization" as a metaphor. "Self-organization," however, has a meaning in the context of Prigogine's (1980) thermodynamics of far-from-equilibrium systems that differs from its use in Maturana and Varela's (1984) neurophysiology-based model of *autopoiesis*. Luhmann (1986) proposed using the latter model to analyse the communication of meaning in social and psychological systems. The distinction between social and psychological systems was based on Husserl's (1929) philosophy, but radicalized by Luhmann to the extent that these two types of systems are considered as operationally closed and therefore as constituting environments for each other. In other words, social systems can be expected to process meaning differently from psychological systems.

The cybernetic model of self-organization may have its origins in biology or physics, but the crucial question is whether the metaphor helps to explain problems and puzzles in the system(s) under study (Holland, 1998). Unlike biology, the social sciences study intentional subjects and their social configurations. The non-linear dynamics of meaning are hitherto poorly understood as a subject of complexity science. Meaning is provided from the perspective of hindsight, and thus the arrow of time is locally reversed (Coveney & Highfield, 1990; Leydesdorff, 1994; Mackenzie, 2001; Urry, 2003). This may reduce the uncertainty that would otherwise be expected to increase because the Second Law is valid both for thermodynamics and for the dynamics of probabilistic entropy (Theil, 1972).

The mechanism of providing meaning can be modeled using the theory of anticipatory systems (Rosen, 1985). An anticipatory system is a system that is able to entertain one or more models of itself. The model provides the modeled system with specific meaning. Dubois (1998) found a way to formalize this as an *incursive* equation. Using these equations, a distinction can be made between weakly and strongly anticipatory systems. The latter are able not only to model themselves, but also to co-construct their next future states.

In this context, I proposed using this distinction to model the difference between psychological and social systems: while psychological systems are able to entertain models of themselves, social systems are able to co-construct their own next states, for example, in the case of techno-economic co-evolutions (Leydesdorff, in press). Using Dubois's equations, it is possible to derive formulations for the three levels at which meaning can be communicated according to Luhmann (1997): interaction, organization, and self-organization. However, it follows from these equations that the system would accumulate complexity if agency did not step in to make selective choices. The social system can therefore be considered as semi-autopoietic: the further development of the system remains dependent on agency to co-evolve, for example, in terms of communicative competencies (Habermas, 1981).

Within Luhmann's theory, this additional coupling between agents and structures can be appreciated as "interpenetration" (Luhmann, 2002; Parsons, 1968). Unlike the biological mechanism of structural coupling and operational closure, social and psychological systems have access to each other's operations. This additional degree of freedom can be considered as grounded in the emergence of human language as an evolutionary step (Leydesdorff, 2000). The controversy signaled by Habermas (1987, p. 385) between "linguistically generated intersubjectivity" and "self-referentially closed systems" can thus be considered as a puzzle which complex systems theory may be able to solve.

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Complexity in education: Does chaos and complexity require a different way of learning and teaching?

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1. Introduction

The article by Jörg, Davis, and Nickmans (2007) provides a thought provoking account of what they perceive as a crisis in education and learning that precipitates the need for a new paradigm or science that centres around the notion of complexity. Briefly, the authors' argument is that current educational practices and learning theories do not take into account the complexity of education and learning, and that thinking in complexity may lead us to a different science of learning and education that is characterised by acknowledging the complexity of reality and its non-linearity.

It is further suggested that a theory of the educational crisis, as well as how to escape the crisis, is necessary if we are going to escape old habits of thought. This will culminate in a new science of learning characterised by a marriage of the evolutionary paradigm with the complexity paradigm leading to transdisciplinary tools of thought and a theory of change. The authors see the main value of the new paradigm in terms of the possibility to experiment with conditions that would be likely to stimulate complexity, abandoning pre-determined outcomes in education and embracing transdisciplinarity for a deeper understanding of phenomena.

The article by Jörg et al. (2007) comes some three decades after scientists and the general public first began to take notice of the unexpected order emerging from chaos in complex systems (Gleick, 1987; Prigogine & Stengers, 1984), and roughly two decades after educators began to take notice of the development of the chaos and complexity sciences (Crowell, 1989; Cziko, 1989; Doll, 1987, 1989; Sawada & Caley, 1985). Of course, one immediately wonders what new insights have been gained in the last two decades to support Jörg et al.'s (2007) powerful assertion that the complexity paradigm can be the cure to all educational ills. Publications focusing on ideas from chaos and complexity science – used principally as "a source of novel metaphors" (Mackenzie, 2005:57) – in education have risen steadily. In this article I will attempt to place Jörg et al.'s (2007) position paper in perspective by examining the contributions of various authors whom they have unfortunately excluded from their argument. As we shall see, while most have embraced the principles of chaos and complexity, others have been wary of its application to education. And it seems that while educational researchers have been arguing around questions of relevance, the science of chaos and complexity have found fruitful application in other disciplines outside the hard sciences

as diverse as social psychology (Vallacher & Nowak, 1997), economics (Baumol & Benhabib, 1989), and evolution (Kaufmann, 1993).

I will begin by presenting a short overview of the contributions of scientists in chaos and complexity who appear to have had the most notable influence on scholars' thinking about chaos and complexity in education and then proceed to illustrate how scientists have grappled with the application of principles of chaos and complexity in education over the last 20 years. I will attempt to demonstrate that, as is evident from Jörg et al.'s (2007) article, very little new insights have been offered, in my opinion mainly because (i) arguments continue to centre on the metaphorical application of chaos and complexity theory, (ii) a plausible argument of the educational system as a complex system has not been formulated yet, and (iii) little evidence exists of the application of principles of chaos and complexity theory where those applications led to the solution of educational problems, rendering most assertions of its superiority somewhat questionable.

2. The emergence of the new sciences of chaos and complexity

Although it is quite impossible to trace the birth of chaos theory to any one scientist, and indeed doing so would inevitably exclude many scientists who contributed to its development, it is generally accepted that the birth of chaos was formally introduced to the scientific community with the meteorologist Lorenz's (1963) publication on *Deterministic Nonperiodic Flow*. Continuing with the work of mathematical physicists Ruelle and Takens (1971) and mathematicians Li and Yorke (1975) who first coined the term "chaos" (from a mathematical perspective more correctly termed non-linear dynamics), Prigogine and Stengers (1984) and Prigogine (1987), scientists studying non-linear systems and turbulent processes eventually began to take increasing notice of the patterns underlying apparently random processes in deterministic systems. Although Prigogine and Stenger's publication of *Order out of Chaos* in 1984 did much to make researchers outside the areas of mathematics and physics aware of a new development in the sciences, it was not until the publication of James Gleick's *Chaos: Making a new science* in 1987 that the public became aware of these new developments on a large scale.

Prior to the publication of these works, over the course of about two decades, scientists in different corners of the world gradually began to place the pieces of a puzzle together that would reflect nature's physical systems as consisting of processes that may appear chaotic, but that have an underlying orderliness in the randomness that most scientists would never have guessed at. Very early on, especially in the study of turbulence (Gleick, 1987), scientists were especially interested in the description of turbulent processes in liquids (i.e. liquids in disequilibrium) that appeared random and discovered the existence of a pattern of attraction which was described by Lorenz in 1963, but was eventually named by Ruelle and Takens (1971) as a "strange attractor" (eventually also named the Lorenz attractor). The concepts of disequilibrium and strange attractors became firmly associated with non-linear systems and chaos (Mackenzie, 2005). It was especially the notion of disequilibrium as a pre-requisite condition for adaptive self-organisation that appealed to many educators and educational researchers who felt that, for the first time, had at their disposal a credible, scientific explanation that provided the metaphorical language to deal with the implicit complexity of educational processes. Sawada and Caley (1985) have argued that the application of the dissipative structure metaphor to education can lead to new realms of meaning that could ultimately transform educational practice. They suggested that, similar to the orderliness underlying turbulence in fluid dynamics, the prevailing view of classrooms as turbulent, messy and disorderly, should make room for the possibility that disorderliness (i.e. turbulence) can be productive. They also argue that the dominant metaphor for schools as systems-at-equilibrium, that is to say closed, stable and deterministic, should be rejected in favour of a new metaphor which emphasises the school as an open, dissipative system which functions more like a self-organizing community in which turbulence is welcomed as a sign of creativity and a requirement for spontaneous adaptation.

Dissipative structures, as defined by Prigogine and Stengers (1984) are structures which arise as a result of a transformation from disorder to order (p. 12) in which a close, albeit paradoxical association exist between structure on the one hand, and dissipation on the other hand (p. 143). Taking up Prigogine and Stengers' (1984) point about the turbulent processes that are characteristic of dissipative structures, Sawada and Caley (1985) extends the metaphor to draw our attention to the apparent futility of searching for "sweeping principles of instruction" (p. 17) and the importance of the teacher as "a catalyst in the Becoming of students" (p. 17). Cziko (1989) also drew on the notion of turbulence when he explored the implications of the unpredictability of human nature in educational measurement and others have utilised the concept of order in disorder as a metaphor for educational processes (Davis & Sumara, 2001; Doll, 1989). Thus, what we see quite clearly in these earlier articles, is a particular fondness for an application in a general sense, of principles associated with the idea that the complexity and disorder that educators contend with each day, can be productive and orderly on some kind of meta-level. It is not difficult to understand why. Google Scholar search (search terms *teaching* AND *complex**) yielded about 859,000 hits containing book titles and scholarly articles in 2006 and 1,600,000 hits at the end of 2007, suggesting abundant evidence for the contention that teaching is widely regarded as a very complex matter on various levels, at least in the common sense of the word.

Yet scant attention is paid to the principles of complexity and how these principles apply to educational processes. Metaphors can be dangerous when they are confused with applications (MacPherson, 1997) so we have the responsibility not only to scrutinise, but to test the extent to which principles of chaos and complexity are able to provide superior directives for understanding educational processes. Ample literature exists that describe chaotic and complex systems (see Cilliers, 1998; Gleick, 1987; Waldrop, 1992), but we find almost no examples of literature that attempts to test the applicability of these principles to education. Instead, the starting point of the argument is generally the [untested] assumption that

educational processes (such as schools, the curriculum, classes, learning, and so on) are complex. To my knowledge, detailed theoretical treatment of chaos and complexity concepts such as sensitive dependence to initial conditions, non-linearity, chaotic/strange attractors, bifurcations, emergence, self-organisation, turbulence, dissipation in the context of education does not exist in education literature. Instead, what we find in abundance are statements such as Doll's (1987) suggestion that "reality is not simple, spiritual, and uniform. It is complex, temporal, and multiple. We need an educational model to fit this reality. We need a transformative, not a measured, curriculum" (p. 16). Or MacPherson's (1997) contention that "there is something immediately attractive about the metaphor of strange attractors rising out of chaotic systems for the study of the curriculum. That is the way general curriculum seems to work" (p. 272). Now we hear Jörg et al.'s (2007) state that "thinking in complexity may, or should, lead to a different science of learning and education, one that is characterised by acknowledging the complexity of reality" (p. 6).

The concept of the strange attractor as a kind of basin of attraction to which the complex system settles, has received scant attention apart from MacPherson's (1995) laundry list of metaphor attractors in education as the myths that characterise educational patterns and trends. As one of the most compelling pieces of evidence demonstrating a complex system, strange attractors can provide visual evidence of underlying order in apparently chaotic systems (Lorenz, 1993; Ruelle & Takens, 1971). In an apparent marriage of order and chaos, the strange attractor embodies the principle of a deterministic system [order] with sensitivity to initial conditions [chaos] that makes complex systems peculiarly familiar but strangely unpredictable. One reason that strange attractors have not been debated so hotly among educationalists may simply be that the concept is quite difficult for non-specialists to understand. Educationalists have an "intuitive feel" for the implication of concepts like disequilibrium and turbulence, but the concept of a strange attractor does not make any familiar educational image come to mind. Another reason may be that educational researchers have not yet applied themselves systematically to a proper understanding of the educational equivalent of the strange attractor, or determining if such an equivalent even exists. To engage with this problem, it would be necessary to demonstrate that a class or school (often described as complex systems) tend to settle down to some kind of pattern of behaviour which never quite repeats itself, i.e. chaotic, but which never quite transcends certain boundaries, i.e. deterministic. But even more disturbing than the question whether such description is, in principle, possible, is the question of deciding which parameters to include as a description of the class or school system's position in space over time. Strange attractors can be illustrated visually because it is possible to plot a cross section of a turbulent system's movement in space over time (Gleick, 1987). What are the essential bits of data that can define a class or a school's position in a particular space and time? What does it even mean to speak of a class or school's position in space? Assuming we exclude physical space [the problem of physical space can be solved easily with the provision of physical coordinates of the class or school that will remain stable, i.e. in equilibrium, over time], do we perhaps mean social space, or political space or educational space? MacPherson (1997) described attractors in education as myths, and he provides provocative names for them, e.g. the Platonic attractor, the Republican attractor, the Scientific attractor, the Do-it-Yourself attractor, the Curriculum Engineering attractor, the Service of God attractor, the Neo-Marxist attractor and the Reservoir Attractor. Upon closer reading and ignoring their almost activistic flavour, one finds that these myths really represent trends in educational philosophy that have tended to dominate educational practice at certain periods in time. Further, we see that their descriptions really bear little, if any direct evidence to scientific descriptions of attractors other than the fact that they can be thought of as an [arbitrary and idiosyncratic] description some kind of pattern. Strictly speaking, an attractor cannot be a descriptive category that can be used to characterise a system because it is a picture of the system. What complicates matters, is that an attractor is really supposed to be a picture of the *history of a system* as reflected by changes in the values of system variables over time. So, to find an application for the attractor construct in education, or even to apply the metaphor of an attractor in a way that would provide us with a whole new way of conceptualising educational processes, as was suggested by Hunter and Benson (1997), we need to do a whole lot better than simply using the term as another fancy way of expressing that which we already know. If complexity theory is to transform educational practice, it must provide us with a new understanding of educational issues, not just a different, albeit more "scientific" way of phrasing the same problems. Whether this is in fact possible, is open to debate. For one, such an application would have to account for certain variables that would be regarded as essential to the description of the system. Here is where we encounter the first obstacle. Much of what is written in education concerns disparate *descriptions* of observations of which no uniform agreement exists, and we would be hard pressed to find *variables* which could correspond to some kind of observable process in education. In any case, identifying attractors in education carries with it the automatic assumption that education and educational processes are not only complex (for we know that they are), but non-linearly so in the sense of being governed by processes that show sensitive dependence to initial conditions. As it turns out, we find that although assumptions of non-linearity may be intuitively and metaphorically descriptive of education, there has to date not been any formal and systematic attempts at testing whether these assumptions allow us to conceptualise and design educational processes better than existing theories do.

3. A closer look at the application of chaos and complexity to education

Almost without exception, the earliest articles on chaos and education drew on Prigogine's (1984) work on self-organisation in dissipative structures to discuss the relevance of certain principles in complexity to education and to document the major developments in chaos theory that were thought to be relevant to an analysis of educational pro-

cesses. Several concepts related to chaos and complexity began to find a home in the discourse of educational scholars. Early scholars interested in applying chaos theory to education were especially enthusiastic about the potential of chaos theory to transform our understanding of educational processes.

Crowell (1989) applied Prigogine and Stenger's (1984) work on dissipative structures to discuss how the new scientific discoveries associated with chaos and complexity fundamentally challenges the Cartesian–Newtonian view of the world as linear, predictable and mechanistic. Thus, even twenty years earlier there was already a sense that current scientific theories could not account for the complexity in the world we see around us and complexity theory seemed to strike a chord especially with social scientists who felt at last that they had a metaphor, or a vocabulary to describe what they intuitively believed about their work. Describing it as an epochal change, Doll (1989) and later MacPherson (1995) predicted that complexity theory would soon have a strong influence on the way teaching and learning were conceptualised. All of these authors emphasised how complexity would have the potential to change the way we perceive reality and argued for recognition of the interconnected, fluid and emergent quality of life rather than pursuit of the reductionist, fragmented path of modern science. In addition to taking issue with the dominance of an outdated Newtonian paradigm in education, scholars like Cziko (1989) felt that complexity theory would necessitate a reconsideration of the utility, that is to say, generalisability and applicability of "scientific" educational research. In our own research, we argued that the principles of complexity theory could be used to devise cognitive interventions that could better accommodate the nature of thinking as well as the diversity inherent in our schools (Human & Bouwer, 2005).

As a direct result of the notion that complex systems are unpredictable and that long-term predictions are therefore not feasible, Cziko (1989) argued for the use of descriptive and interpretive research to understand rather than predict educational processes and environments. Much later, this point is also emphasised by Radford (2006) when he argued that an analytical reductionist approach to educational research should be replaced by an approach which allows research to fulfil a more reactive role that will allow it to support communication between the school and outside agencies. The same point is made by Jörg, Davis, and Nickmans (2007) when they argue that research that should abandon linear lines of inquiry in favour of more intensive, long-term, fine-grained studies aimed at gaining insight into complex processes. Radford (2006) further reiterates Cziko's earlier point about the limited value of generalisability of research findings and adds that the main task of educational research should be to describe how individual schools adapt to changing conditions and to examine how policies and practices develop rather than attempt to influence the direction of change.

In what appears to be the first article on chaos in education, Sawada and Caley (1985) chose a metaphorical approach by discussing dissipative structures in terms of "new metaphors for becoming in education" (p. 13). Arguing that fundamental reconceptualisation is possible through metaphor, Sawada and Caley (1985) further argued the importance and appropriateness of the dissipative structure metaphor which describes the dynamics of systems far-from-equilibrium to education. In essence, Sawada and Caley (1985) aimed to illustrate how the perception of schools as systems at-equilibrium is erroneous and should be replaced by the dissipative structure metaphor that describes schools as systems far-from-equilibrium. Two articles that appeared in the September 1989 issue of *Educational Leadership* had an almost prophetic quality about them as one author claimed that "we must change the way we view the world before we can find the best ways to prepare students for the future" (Crowell, 1989, p. 60) and the other that "Friday morning math took on a new dimension for the 6th graders whose teacher, with a visiting instructor, taught them to use insights from complexity theory" (Doll, 1989, p. 65). Some time later, Garmston and Wellman (1995) would also proclaim that "an examination of the 'new sciences' offers insights into approaches to school improvement and provides practical tools and ideas for school refinement that can lead to improved learning for all students" (p. 7). Around the same time, MacPherson (1995) felt that it "would be better for public education that we come to terms with the implications of chaos while we can direct its flow than after a catatrophic collapse of the dikes" (p. 277) but at the same time cautioned that "it would be foolish to expect any such direct applications either soon or in the foreseeable future. That would be taking the mathematics of chaos *too* seriously." (p. 270). It seems clear that educational thinkers in the late eighties and nineties were entranced by, if not convinced of, the "radical" insights that chaos theory offered as opposed to the traditional scientific paradigm emphasising determinism and predictability, and most were eager to explain how this new scientific knowledge would eventually affect educational thinking. But there were also those who felt that chaos theory had no real place in education. Hunter and Benson (1997) in particular criticised MacPherson's liberal use of the chaos metaphor in education and suggested that, for chaos theory to be applied to education, it must be demonstrated that chaos constructs have more predictive and explanatory power than current educational constructs and that chaos theory provide a new way of understanding education. In a rejoinder, MacPherson (1997) agreed with Hunter and Benson (1997) about the application of chaos theory to education, but persisted in saying that, since education is driven by metaphors, there is reason to consider some of the metaphors offered by chaos theory. The tension between these two authors remain unresolved, is unfortunately not addressed by Jörg et al. (2007) and in my opinion, is the crux of most debates about chaos and complexity today. Is the application of chaos and complexity theory to education simply a metaphorical matter, or is there reason to suggest that the principles of chaos and complexity theory may be relevant to education in a more directly applicable manner?

The very first articles all represent broad trends that eventually developed around issues of complexity in education, namely (1) *learning-teaching practices* (Doll, 1989), (2) *learnability issues* (Crowell, 1989) and (3) *schools as organisations* (Garmston & Wellman, 1995). The purpose of these early articles were rarely to offer a critical or evaluative discussion of the principles of chaos theory as they were understood in scientific circles at the time, but instead to focus on broad and liberal interpretations of principles associated with turbulent processes and the application of these interpretations to various educational processes. One might say that it represented a kind of brainstorming about the possible implications that new

developments around complexity in the sciences held for education and to a certain extent it may also have served as a way of spreading the news about new ways of thinking to those in educational circles. For example, Doll (1989) stated that "I will not go into the details of chaotic or non-linear patterning here. I will though, pick one illustration from chaos theory and show how this guided Ron and me in our work with the students" (p. 66). He then proceeds to describe how the image of the "butterfly effect" as an illustration of the principle of sensitivity to initial conditions later described eloquently by Lorenz (1993), served as the primary metaphor that guided their interactions with a group of learners in a mathematics class. Using Prigogine's description of self-organization in dissipative systems, Doll (1989) further described how the metaphor implied to them that they had to "organize the Friday curriculum and our presentation of it in such a manner that we had enough of a 'burr' to stimulate the students into rethinking their habitual methods but not so much of a burr that re-organization would fall apart or not be attempted" (p. 68). In addition, Crowell (1989) related the principles of chaos theory as being reflected in educational practices such as cooperative learning, complex instruction, the whole language approach to literacy, as well as brain-based learning by virtue of the fact that chaos in complex systems is a manifestation of the unpredictability and interrelatedness of these systems. Complexity, interrelatedness, unpredictability and apparent chaos have long been issues in education that have remained difficult to address and understand, let alone to control and resolve. These early authors felt that the developments around complexity, viewed by many as a radical paradigm shift, could help educational researchers to better understand the complexity of educational processes.

Eventually, scholars began to apply ideas associated with complexity theory to what seems almost every conceivable area in education from *learning and teaching* (Davis & Sumara, 1997), the development of *school leadership* (Garmston & Wellman, 1995), to the *pedagogical accessibility* of chaos theory (Duit, Komorek, & Wilbers, 1997) and *curriculum design* (Doll, 1986; Macpherson, 1995, 1997). Recently, the popularity of complexity science among educators has given rise to the birth of an on-line journal called *Complicity: An International Journal of Complexity and Education*. The first two issues of the journal covers articles relating complexity theory to *school architecture* (Upitis, 2004), *writing* (Nelson, 2004), the teaching of *mathematics* (Sinclair, 2004), reconceptualising *education* (Osberg, 2005), *systems-related therapy* in the classroom (Burris, 2005), education as *becoming* (Semetsky, 2005) and *attractors in school management* (Gilstrap, 2005).

Thus, it is rather clear that scholars have grappled with the relevance of concepts associated with complexity theory to education for a long time. As we shall see, and perhaps by necessity, these applications have continued to focus on a metaphorical approach and have principally centred around the meaning that concepts such as emergence (self-organisation), sensitive dependence (unpredictability), and disequilibrium (edge of chaos; feedback loops) acquire in an educational context, especially when focusing on diverse issues as teacher education, curriculum reform, school architecture and learning.

As Jörg et al. (2007) will know, all scholars who have emphasised the importance of complexity theory in reconceptualising educational issues have, without exception, underlined their dissatisfaction with current educational models that they believe are the fruitless outcomes of an outdated application of Newtonian principles. What these scholars have not been able to argue, is whether sufficient evidence exist that a complexity paradigm will fare better in addressing the educational issues of our time. For example, focusing on the application of complexity to *learning-teaching issues*, Davis and Sumara (1997) have proposed an enactivist model of learning how to teach by arguing that learning and teaching are inseparable processes that do not occur in the minds of the actors, but in the possibilities for shared action. In doing so, they draw on the notion that classrooms, schools, neighbourhoods and so on, are increasingly complex systems of which the individual is only one subsystem. Drawing on a variety of ideas from philosophers such as Derrida and Heidegger, and blending Vygotsky's sociocultural perspective with Capra's thoughtful explication of complexity theory in his 1996 work called *The Web of Life*, Davis and Sumara (1997) argue that teaching and learning are cultural activities that can benefit from a view more consistent with complex systems theory. They specifically argue that the control of learners and pre-set outcomes should be abandoned in favour of more "holistic, all-at-once co-emergent curricula that are as much defined by circumstance, serendipity, and happenstance as they are by predetermined learning objectives" (p. 122).

The idea of the school as a community in which learning "happens" as the agents [teachers and children] are engaging in mindful interaction, all the while learning and constructing meaning in learning-rich environments especially rings a bell with educationists interested in complexity theory. The main reason is that complexity theory seems to offer an explanatory theoretical framework that can be very helpful in acknowledging the everyday complexity and systemic interconnectedness inherent in teaching and learning environments. Of course, that it is regarded as a scientifically proven paradigm, also helps. In a later article focusing on learning communities, Davis and Sumara (2001) make use of general principles of self-organisation and disequilibrium of complexity theory to frame their intuitive understanding of collaborative learning practices in the classroom and argue that the principles of self-organisation and disequilibrium are essential building blocks to a proper understanding of teaching and learning. In my own research (Human & Bouwer, 2005), I have experimented with ways in which complex learning environments can be created to support the notion of cognition and learning as complex and emergent. We have also made concrete suggestions about the kinds of behaviours that teachers might engage with to support the emergent complexity of children's thinking.

In terms of *learnability issues* in complexity and education, contributions have mainly come from in the field of science education. Focusing on chaos theory, Duit, Komorek and Wilbers (1997) have suggested that certain core principles in chaos theory such as the limited predictability of deterministic systems can be taught and understood by children as young as 15 years of age. In their studies, Duit et al. (1997) have used their model of educational reconstruction to describe an iterative process of curriculum development that involves an interplay between the clarification of elementary concepts in chaos theory, the empirical investigation of students conceptions and the development of pilot instructional materials

and procedures. More recently, Hmelo-Silver and Azevedo (2006) have suggested that one of the core challenges related to learning about complex systems includes special understanding of learners' cognitive, metacognitive and self-regulatory processes. They argue that the successful deployment and coordination of metacognitive and self-regulatory processes are essential for students to manage and support their emergent understanding of complex systems. More specifically, Hmelo-Silver and Azevedo (2006) suggest that learning about complex systems through computer modeling and simulations such as Starlogo (Resnick, 1997) requires the deployment of generic knowledge about the nature of models, domain knowledge and scientific reasoning skills such as hypothesis generation, experimentation and data collection and analysis. But why should it be important for students to learn about complex systems? Jacobson and Wilensky (2006) believe that complexity theory represents an important shift in scientific perspectives that students will be confronted with in their scientific and professional environments. The implication of this is that students must become increasingly familiar and comfortable with an epistemological framework that accommodates contradictory and counterintuitive propositions about systems as being simultaneously deterministic yet unpredictable, chaotic yet structured. Learning about complex systems requires one to view noisy data not as an inevitable error in measurement, but as an inherent characteristic of the system under investigation which can have profound effects on our predications about these systems. It also requires a relinquishing of the long-held, Laplacian notion that the world and everything in it can ultimately be described and predicted exactly as much as it requires us to concede that we may never be able to steer or control any kind of system by carefully scientifically engineered interventions. Complex systems are unpredictable, and although they do follow local deterministic rules, it is the interaction of feedback among the myriad of elements in the system on a local level that unpredictability emerges. What these authors have in common, is a tacit recognition of the fact that, for students to learn about complex systems, we need to redefine our conceptualisation of the very nature of learning. Therefore, in line with Hmelo-Silver and Azevedo's (2006) allusions to metacognitive and self-regulatory processes as a requirement for learning about complex systems, I would then suggest that the learnability of complexity theory is very closely tied to the learning process itself and how we conceptualise it. Thus, explaining the complexity of the learning process would be an important area of further investigation.

However, there have been very few attempts in the field of education at a systematic examination of learning from a complexity perspective. Recently, Carver and Scheier (2005, p. 70) have suggested that "an easy and intuitive application of the attractor concept to human behaviour is to link it with the goal concept. It seems reasonable to suggest then, that a goal represents a kind of attractor. Furthermore, if an attractor represents a goal, it seems reasonable that a repeller represents an anti-goal." Their primary concern is how self-regulatory processes are employed to structure behaviour in the service of goal attainment, but unfortunately the authors do not offer any systematic and/or empirical evidence in support of their goals-as-attractors hypothesis. Rather, they seem to appeal to the reasonable reader to agree that the idea is, if not substantiated, at least not unreasonable either. And it is not unreasonable. As I have attempted to point out earlier as well (Human-Vogel, 2004; Human-Vogel & Bouwer, 2005), it is very difficult to conceive of cognition and learning as anything but complex. There is a fairly substantive body of literature in cognitive and social psychology that offers convincing, if not empirical evidence, in support of cognition and social processes as non-linear dynamical systems (see Cilliers 1998; Vallacher & Nowak, 1997). However, if we agree that attractors are a way of representing the behaviour of a system (Larsen-Freeman, 1997) and that it indicates the variables necessary to describe the system's dynamics (Vallacher & Nowak, 1997), then it appears that any application of the attractor concept to domains outside those in which it was conceived, should involve a very careful description of the variables that are assumed to describe the dynamical behaviour of the system. Thus, although attractors are often represented as visual patterns of the dynamical system, one should be very careful to assume that attractors, at least in an educational context, are synonymous with trends (as patterns) in education as MacPherson (1995) has done. The main reason is that trends in education represent categories that have been formed by grouping similar events because they have some meaning to the observer. Unless there is empirical evidence to suggest that the events concerned can be demonstrated to represent the essential variables necessary to describe the behaviour of the system, it cannot be assumed that categories are attractors. Without showing what kind of attractor (fixed point, periodic or chaotic) is involved in our description of educational attractors, we really are no further in advancing our knowledge about educational theory as a result of such applications of chaos and complexity to educational processes. Lastly, the application of the kinds of attractors that MacPherson (1995) suggests, begs for a more detailed description of the role that bifurcations would play in flipping a system from one attractor to another.

A central issue to complex systems is usually the notion that complex systems have *emergent properties* that arise at system level and that are not evident when analysing the components of the system. An important point here, as Lesh (2006) have pointed out, is that the properties of a system that result from interactions among its agents are not the same as properties that can be logically deduced from the properties of the agents and that these same properties do not occur in systems where the relevant agents are not in action. Davis and Simmt (2003) have understood emergence to be "those instances where coherent collectives arise through the co-specifying activities of individuals." (p. 140). Emergent properties are generally understood to refer to something "more". Some examples could include the mind, or the concept of consciousness, as an emergent property of the millions of interactions among neurons in the brain. No matter how carefully scientists describe the individual workings of neurons in various centers of the brain, we still cannot provide an adequate description for the mind or consciousness. On a psychological level, personality can be regarded as an emergent property of the millions of behavioural choices that an individual makes over a lifetime. On a broader level, the economy is a remarkable example of an emergent property of millions of transactions among agents that occur independently across the world.

Taking these examples into account, as well as our definition of emergent properties as a central feature of complex systems, and taking into account that complex systems are decentralised systems in which orderly behaviour arises from the random reiterative interactions of its agents, I am somewhat at a loss to describe a class, a school, or education as a complex system. Let us focus on the class. If classes are complex systems, then we can expect them to have some kind of emergent property. What would that be? What would constitute random, non-linear interactions between the students [as agents of the system] and the teacher? Seeing that complex systems are decentralised, what does that say about the teacher's role in directing, mediating and at times, even controlling the course of events in a class? Jörg et al.'s (2007) suggest that the abandonment of pre-determined outcomes might be one way of manipulating certain conditions so that classes are more like complex systems. I would like to argue that complex systems cannot be made by "tinkering" with certain conditions as Jörg et al. (2007) would have us believe. Complex systems emerge quite on their own as a result of the repeated interactions between multiple agents behaving according to a few simple rules. Complexity is born from simplicity. Manipulating the initial conditions of a system cannot make it complex if it is not inherently complex to begin with. Thus, to suggest that classes can be changed to resemble a complex system more closely is a fallacy.

4. Conclusion

I do believe that cognition is complex in the non-linear sense of the word. I also think that the interactions between teachers and the children in their classes are essentially non-linear. One might even go so far as to state that those interactions have an emergent property that can perhaps be described as the atmosphere or the culture of the particular classroom, but one would be hard pressed to explain the role of the teacher because teachers can and do play a powerful role in shaping the learning environment in their class. However, complex systems do accommodate the fact that some agents may have a stronger impact in their interactions than others. Nevertheless, the general assertion that schools, or education are complex systems I find, generally, to be without substance and hinged on untested assumptions. That education and schools are complex as the general public would understand it, is unquestionable. That education and schools are complex in the scientific sense of the word, has not yet been demonstrated. In that regard, I do agree with Jörg et al.'s (2007) that we need a theory to account for teaching and learning as complex processes. I would like to add that such a theory should be solid enough to provide educators and policy makers with tangible ways of testing its applicability before we can adapt current practices in education with confidence and declare that the new science of complexity offers a better alternative to address educational issues than current paradigms.

In conclusion, Mackenzie (2005:61) suggests that "complexity is generally not exportable as a model or solution, only as a *problem* or a problematization of generality" and yet we see a proliferation of models in education based on the application of the principles of complexity. The complexity metaphor is readily applied as a model for understanding learning processes and school systems, mainly because the language of complexity resonates with the intricacies and unpredictabilities of education and provides a scientifically valid way of reflecting such ambiguities. Perhaps the question is what one would gain by treating the principles of complexity as a problem for education and not the solution?

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