

A Generative Complexity Theory of Minds

Evolving in Peer Interaction

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(with 5 figures)

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ABSTRACT

The focus is on formulating a complexity theory of minds evolving in the generative process of development through human interaction among peers. This interaction between two persons and their minds are taken as the unit of study. This unit will be regarded as a complex system, with their different parameters. A system, consisting of generative reciprocal influences within complex relationships of mutual, simultaneous reciprocal causal relations. The complexity of it still lacks an adequate vocabulary. What is needed, is a link between thinking in complexity, an adequate theory of personal development through human interaction, and the conceptual thinking of evolution theory as a methodological tool. The processes involved are both auto- and cross-catalytic of nature, leading to self-enhanced causal loop effects. The unexpected effects of human interaction may be described and explained as non-linear effects of 'bootstrapping' each other as a result of the causal dynamics of human interaction within peer relations.

Keywords complexity theory - evolution theory – learning and development – theory of mind – reciprocal causality – human interaction – reciprocal relationships – nonlinear enhancement – dynamic interweaving

Introduction

Social science has been in crisis since long, partly by being the captive of old ideas and habits of thought. These can be ascribed to the historical tendency of trying to be scientific by copying natural science, i.e. of physics. Such a tendency has been called physicalism [1; 2]. This approach may be described as a rational, objectivistic, and mechanistic one. All of this led to what Morin has called the 'blinding paradigms' [3]. For the Russian psychologist Lev Vygotsky it was an essential part of what he called 'the crisis of psychology' in his days, at the beginning of the 20th Century. He noticed that mind has not been taken as a serious subject for scientific study. The crisis he described in his work has been a driving force for him all the time of his life. He tried to find a real synthesis of the natural and social sciences. He was convinced that you cannot find a science; you have to invent a new science!

Recently, natural sciences have shown a real change in the expanding fields of chaos and complexity theories, with their recognition of the complexity of reality. Complexity itself became a serious topic for study. The social sciences have followed this new kind of thinking in complexity about the different subjects of complexity. The traditional complexity of the mind, now, has become a topic of interest as well. This has also consequences for the field of learning and development, and their place in the educational system. It seems time to move beyond the rhetoric, the rhetoric which still dominates the field of education [5]. We should find new ways for studying complexity in that field. Firstly, we should take complexity not too easily for granted [6], i.e. for the topic of human interaction between persons within their relationships as time-dependent processes. What is needed is a process theory of human interaction within reciprocal relationships. Secondly, we should overcome thinking in separate disciplines. It seems time to view the different disciplines anew: by trying to find an integrative perspective. Such a perspective can be as well interdisciplinary, cross-disciplinary, or trans-disciplinary. From this perspective it seems very promising to link a theory of learning and development of persons with the fields of complexity theory and evolution theory.

In this paper it is shown in what way thinking in complexity may be helpful to escape the old ideas and the blind spots of social sciences, towards a new view of science. A science of complex phenomena like the process of human interaction and its connection with evolving minds in time. A science which may be of help to deal with the complexity of reality as we may view it. It may, however, mean that we do not simply accept reality as we experience it, but may recognize the possibilities for re-inventing reality too! This challenge means a new approach of the concept of interaction from a complexity perspective [6;7], replacing the concepts of action and of reaction as foundational for the social sciences [8;9;7]. Below a sketch will be given of the line of reasoning in this paper.

Firstly, I shall give a short impression of the history of education as a science, and the crisis in psychology according to Vygotsky in his historical, but still relevant work [9]. His later work laid the foundation of a generative theory of development through interaction which dealt with how mental structures and mental functions were generated in child development. He was correct in that we needed a new methodology for (educational) psychology to go beyond the descriptive and become

explanatory in our approach of learning and development. One of his main problems, however, was that he did not know how to deal with causality and the causal dynamics in interaction. He seemed to prefer to draw on a Darwinian approach which is, of course, evolutionary, but Vygotsky took the development of species in that approach as fundamental for individual development as unique as well [10, p. 99; see also 11, p 449]. That's why he was strongly in favour of an evolutionary description of development as one of change and transformation, of qualitative transformations, even of metamorphosis, resulting from the different processes going on: not only of evolution but also of involution, and revolution [12, p. 73; see also the view of Aleksandr Bogdanov, in 13]. It is my intention to show how his view on development through interaction may be linked to a theory of generating complexity through interaction, to be called a "Generative Complexity Theory" (GCT). The concepts of (causal) influence and the causal dynamics of reciprocal influencing each other in human interaction are central concepts in this. These should be encompassed within theorizing on the processes of change, involving change of the nature of these very processes itself, such as in the brains, as stated by Minsky: "*The principal activities of brains are making changes in themselves.*" [14, p 139] This is similar to the notion of child development of Vygotsky, focusing on what he described as "*a radical alteration in the very structure of behaviour*" [12, pp 72-73; emphasis added]. This new notion, with its implicit radical alteration, enables the essentially non-linear view on development: of turning points, upheavals and leaps in that development [12, p 73]. The mind, then, may be viewed as a medium in these processes (cf. Luhmann, 2002, p. 175). The focus on reality, then, as the object of study, becomes *not* a reality to be described as 'unfolding', as Luhmann tries to convince us [8, p 52], but a reality which has to be *invented*.

A different reality

To reinvent reality of processes of development means to conceive of a reality which can be characterized by complexity, i.e. of minds evolving through human interaction, implying a complexity which is inherently dynamic, indeterminate and unpredictable in its effects. A reality which Kiefer delineates as "composed of multiple-simultaneous, interdependent cause-effect relationships," in terms of a dynamic complexity [15, p 267]. What is needed is an adequate vocabulary to describe mutually causal relations in dyads [16]. The causal dynamics involved in those mutually evolving relationships is the topic of our modelling complexity in reality; a complexity which seems hitherto unknown because of inadequate conceptualization and methods. To describe such a complexity as a *new* reality we need a Generative Complexity Theory (GCT). This new Complexity Theory will be linked with the recently developed Evolutionary Psychology approach [e.g. 17; see also 18, and 11]. This approach had its foundation in the work of James Baldwin, as Plotkin shows so convincingly [17]. It enables to describe the concept of mind in a new way. This was also a main topic for Vygotsky, as sketched in the work of "Mind in Society." [12] In line with his thinking, and the thoughts of others on mind and interaction, the central question is not only how two minds may operate together, but in particular '*Why and how* two minds can be better than one' [see 19, p. 89].

To deal with how two minds may operate together and may unite themselves in a process of dynamic progressive emergent 'construction', of so-called "learnability" [cf. 19; 20], we need an adequate process theory of human interaction [6]. The development of mind and its inherent complexity could be described now as "*the adventures of a couple of (micro) evolution of two minds evolving in their interaction*" [7]. This adventure, encompassing both evolution, involution, and revolution, may lead us along unfamiliar paths. It may lead to descriptions of nonlinear, so-called 'loxodromic' paths in an n-dimensional (hyper-) space. The minds developing in time can be described as dynamic landscapes of consciousness [21], or as 'landscapes of the mind', evolving dynamically in time [22]. For now, one may say that we should *complexify* reality, in terms of thinking in complexity *about* reality [see 23]. Such new thinking may, if fully integrated in a new general causal explanatory framework, may lead to a new description of reality in education as well [24, p 21; 7]. The focus, then, is a complex reality, a reality to be re-invented, based on the new notion of causality as fundamentally non-linear in its potentialities. Modelling causality this way may, consequently, be regarded as the foundation of a new pedagogy: a Complex Generative Pedagogy (CGP). By taking interaction of two minds as ego and alter in interaction [Baldwin, in 17, p 76], and their complex dynamic interweaving as a starting point of learning and development, of minds in their complex affective and cognitive evolution, this new

pedagogy may be described as a real ‘*humanistic pedagogy*.’ It becomes humanistic by focusing on minds in their evolution, as socially constructing each other, in terms of *co*-constructing each other (Brownell, 1989), *in* and *through* interaction in time [see also 27, p. 172]. The complexity of the process can be characterized by their generativeness and creativity, like Bruner did [21]. He describes such a process as a non-linear process of ‘bootstrapping’ each other through communicative human interaction in a small community or group [28], i.e. within a dyadic reciprocal relationship among peers. This process of ‘bootstrapping’ each other as a process of creativity implies both spontaneity and randomness, which actually goes *beyond* the notions of ‘construction’ and ‘determinism’. It seems more like an evolutionary kind of determinism: fundamentally *unpredictable* in its course but understandable in its (causally) generative mechanisms of the processes involved. The development of (two) minds in their interaction, now, may be described as a micro-evolutionary process of adaptation through the unpredictable, generative process of interaction of two minds evolving. Such a complex process and its effects can be represented in evolutionary terms of so-called ‘adaptive landscapes’ by Sewall Wright [in 29, p 69], or as dynamic ‘mindscapes’ in an N-dimensional state space (Globus, 1995; see also Jörg, 2004). This kind of development through interaction can be illustrated metaphorically by the drawing of M.C. Escher, in figure 1 below.

Figure 1 Sketch of M.C. Escher’s ‘Whirlpools’ as connecting dynamic ‘loxodromic’ paths through interaction

The drawing may be described by what Valsiner calls a ‘cyclical-helical unity’ [31, p. 251]. It shows an unusual kind of unity. A unity which cannot be separated! It shows the spirals of development of an ensemble in two dimensions: both as evolution by going from the inside to the outside, and as involution, by going from the outside to the inside. It does not show, yet, how the two spirals of development are formed through connecting in time.

Education as a science

The history of education science (and of educational psychology) could be described as a history of the struggle to become scientific. This struggle, however, led to a crisis in that science, according to Vygotsky [9; 32]. That crisis still seems to be the crisis of today too [33; 34; 24]. In his work on the meaning of the crisis in psychology Vygotsky not only described the crisis in his days, but also tried to delineate how the crisis should be solved. Education science was in need of what he called ‘a theory of the crisis.’ [cf. 27, about the need for a Theory of Science, a *theory about the system of education in the system of education*; italics in original, p 365] Vygotsky noticed that (educational) psychology as a science tried to be a copy of the natural sciences to make itself respectable as a science. He made his position in this very clear, in his comment on the Marxists psychologists trying to formulate their own science: you cannot *find* a science, you have to *invent* it [9]. To do so, you first have to develop an adequate methodology [12]. He formulated some important principles to be connected to such a methodology. The first principle may be formulated as follows: one should not only study the object but also analyze the process, formulated in his own words as “the process must be turned back to its initial stages.” [12, p 62] The second principle concerned the need for an explanatory instead of the commonly used descriptive approach. This implied the study of the *causal dynamic basis* of the problem under scrutiny [12, p 63; emphasis added]. In the footsteps of Vygotsky one still may formulate the goal of (educational) psychology as the search for an adequate explanatory causal dynamic basis for the study of phenomena and problems and their underlying process to be studied. This goal, now, may be reformulated as a challenge for the field of Complexity Theories as well [see 23, p vii]. It is not enough to recognize complexity in education as practice. Complexity still seems to be a kind of black box in our thinking about education [35, p 261]. We should be aware that we cannot think of complexity in education without thinking about the processes involved in it. To study the subject we have to go back to the initial stages of the process [12]. One may call this problem, in a different way, the problem of temporalization of complexity [7, p 246] If we negate that problem, we may easily loose ourselves into the idea of a purpose as the sole reference point, an idea which “quickly degenerates to a notion of an attainable end state of education.” [27, p 246; see also 3, about

the perverted thinking in terms of ends-means in education). These (first referenced) authors are very clear on that point: "But the complexity of the process could not be sufficiently be ordered by starting at the end." [27, p 246]. Only by taking account of the processes involved, we may be able to "capture the specificity of the education process and - in doing that - make its application possible." [27, p 160]. The fundamental question, then, becomes:

Is it possible to invent a science of education, focussing on a different reality of education, with its phenomena of minds evolving in time as subjects to be studied, to be taken as inherently complex?

This question offers a real challenge for all of us involved in the field of Complexity Theories and Education Science. It means, firstly, that we should develop a new theory of Generating Complexity which is linked with a new methodology of Complexity *in use for* education. Doing so we may arrive at a Complex Generative Pedagogy which is foundational for a new practice of high quality education. A practice which escapes the old ideas of traditional practice [cf. 20, about the ideas in the field of economy in his days].

Analytic framework

To deal with the challenge sketched above we should take into account the way we are facing with the complexity of reality, including the 'semantic difference' between idea and reality [27, p. 25]. In the history of our science we seem very much inclined to a kind of constructivism, and of Mythic understanding [36], with its inherent myopia and blind spots [cf. 24, p 47]. The history of science may be called a history of different views of constructing reality. At the same time it seems a history of "constructivism and a reality that remained unknown." [37] Reality seems in a way like a kind of a variable. For instance, after the publication of Darwin's main work, reality became very different from the period before he had written this work. In our days it may be illustrated in the same way by the discovery and/or invention of different theories of complexity, showing a complexity of a reality which remained unknown for so long in history. One may describe such a position of researchers and their blind spots as being victims of age-old prejudices [see 9]. *This position seems still very much a part of the reality of education in our schools as well*, because of what may be called "the 'pull' of the traditional school culture." [38] We are so much involved in organizing the practice of education that we easily forget the real nature of learning and understanding of our students [24]. Yet, teaching is inevitably based on notions about the nature of the learner's mind [28, p 46]. Putnam & Borko formulated recently the problem for an alternative pedagogy as one of dealing with the complexity of the problem space in which teachers work [38, p 11]. They do not seem very hopeful about changing the nature or form of teachers' professional interactions, and consequently their way of thinking. They refer to Ball (1994) who noted the lack of critical reflection in many teacher discourse community [38, p 11]. The educational community typically considers knowledge to be something that persons *have* [38, p 12; emphasis in original].

The challenge, now, for our analytic framework is how to bring complexity into the reality of our thinking about education, more specifically into the reality of our very practice of education, and its way of organizing that practice. We should make an end to colonizing that practice for purposes of theorizing about that practice [9], and start taking practice more seriously as a point of departure. We may know much more of practice, including its complexity, than we may be aware of. It is wisdom of the past which may lead us to sound reasoning and 'thinking in complexity.' [see 23] Only then we may become the 'visitors of the future' of a re-invented reality of education [see 21]. A future in which we may 'bootstrap' each other in our learning and understanding through communicative human interaction in small sub-communities [28]. It may be such bootstrapping, taking place in a non-linear way within reciprocal relationships among peers (dyads), that may offer a radical new perspective for learning and education. A perspective which could be founded on new thinking: a thinking in complexity [23].

Rethinking complexity

Recently some real change takes place in the sciences of humanities. Publications appear with titles like "Rethinking Psychology" [39], "Rethinking Education" [40], "Rethinking Educational Psychology" [28], "Problems of (critical) Reflection in the System of Education" [27], "Rethinking Reality" [41]. Barab & Kirshner focused in a Special Issue on the subject of "Rethinking Methodology

in the Learning Sciences.” [42] All of these efforts of rethinking may be regarded as efforts of reflection upon itself. The underlying problem of some of these efforts of rethinking seems to be one of linking theories with a new kind of reality of practice of schooling [24; 43]. We all seem to be thinking and acting like fishes in the water, unable to become aware of the water we are swimming in. This situation is comparable to Vico’s description of the eye which cannot view itself [44, p 97; see also 45, proposition 5.633].

Underlying all of the efforts of rethinking mentioned above seem to be the rejection of what we may call the strong belief in the Calculable [7], of the computational, with its implications for control and predictability [see also 25, p 146]. It is the new belief that there is not only more than the calculable but also a complex reality which is beyond the limits given by that view. “The complexity of the world is real,” as Axelrod & Cohen (1999) would say [46]. A reality which, however, may offer new possibilities. The fundamental question, therefore, seems to us the general question of “How to deal with the complexity of the *non*-calculable, of the *unpredictable*?” It is very true, as Mathiasen and Rasmussen (2003) stated, that you need complexity to deal with complexity [47]. This is the only way to deal with complexity as it manifests itself in practice. So, *in* and *for* practice, “linear thinking may be *dangerous* in a non-linear complex reality.” [23, p 407; emphasis added] But complexity must be not only be recognized. One should also be aware of the possibility how it can be generated.

Education, now, seems strongly in need of recognizing (emergent) complexity at work in practice and, even more, of the full understanding of such complexity. In our view it should lead to a ‘holistic anti-, or non-reductionist’ approach [see 48, p 285; 49; cf. 50, p. lii]. In line with this kind of thinking, the *main issue* seems to be that for each of the different (‘scientific’) systems, in practice, “the system cannot handle its own self-created complexity.” [27, p 248] The next question may be put as how to overcome such a situation of lacking reflexivity? The problem seems to be *not* so much to lie in the *new ideas* but of the difficulty of ‘escaping from *old* ideas’ and from ‘habitual modes of thought and expression’ [20, p. viii; emphasis added; and 10, p 97; see also 8, p 187]. *You have to step outside of the system*. This seems also the message of Luhmann [37] about constructivism, and, as a consequence of it, the possibility of a reality that remains unknown. So, part of the answer seems to be in developing the art of stepping outside of the system we are in, and by taking a different view: a view from the outside. Can we, for instance, leave constructivism behind and develop an open eye for another reality if we really want so? A different, more complex reality of education? A complex reality which, notwithstanding its closeness to our way of looking at reality, still seems to be taken for granted and *therefore* beyond our abilities of explanation: “We see complex phenomena around us so often that we take them for granted without looking for further explanation.” [5, p 1] But “The complexity of the world is not only real,” as we saw above [46], but may also be a reason to be optimistic, in terms of the possibility of harnessing complexity! So it seems that we may be able to extend our power of imagination and explanation and become able, as well, to *create* new possibilities for explaining the complexity of reality [see 25, p 9]: *also in education*! This is essentially what inventing a new science of learning and education should be about. Some describe this possibility of invention in terms of a *feeling*, like Dills & Romiszowski (1997) did [51]. They linked the urge of invention something new explicitly with a lack of awareness: “There is a growing *feeling* that there is much more to be learned than we currently are aware of about the processes of learning and instruction.” [51, p. xxiii; emphasis added] According to Robbins (1999) this may also be regarded as the fundamental message of the work of Vygotsky: “In speaking metaphorically, much of classical psychology can be compared with Newtonian physics, with its concomitant, although fundamentally incorrect, notion of the calculable, where Vygotsky’s thoughts would then relate to newer areas of physics, such as complexity-chaos theory.” [52, p v]

Complexity from a historical perspective

The key of becoming aware of the complexity of learning can be found in the work of Vygotsky, as Kieran Egan (1997) was well aware too: learning should be conceived as *change and transformation*, the *restructuring of the whole psychological process* brought about or better, mediated, through the system of signs in use in social processes of interaction [see 36, p 29, about Vygotsky’s view, referring to 12, p 35]. It is interaction which seemed to have been one of the main problems Vygotsky dealt with, until the end of his life (1934): the problem of interaction between the child and the people around him, her/his environment [53, p 32]. It may also be called the problem of the unity of analysis

(cf. 54, p 172; and 27, p 194, on the notion of twosomes). This problem has been left unsolved by Vygotsky. It remained since unsolved by others as well (like Piaget), in not giving a fully explanatory causal account of the process going on [see 48]. One may say that interaction seemed too complex to deal with in full extension, even by a genius like Vygotsky! It may therefore be no surprise that the history of science shows that interaction is only a very young concept in that history [see 7]. It is a long history of action, and of reaction, evolving in history towards a couple of action and reaction, ending in the concept of ‘interaction’ at the 2nd half of the 19th Century [7, p 220]. This history may be described as a history of “*complexifying* our mode of perceiving and conceptualising the world of phenomena.” [3, p 135; emphasis added] What we need for learning and education as a science is a *new methodology* in the complexity approach: of the science of complexity as part of our reality [see also 23, p 407]. Such a methodology may *unify* the humanities with the natural sciences [46; 56; 23; 13]. A methodology, having its foundation in mathematics, in which the empirical and theoretical are unified. A methodology which may find its roots in taking the *ensemble* of ego and alter and the inherent complex dynamic processes linked to such an ensemble. This is the fundamental dynamic unity as a complex unit of study: of the single element and its neighbour element, of *co-presence* [57], and of their simultaneous, dynamic processes and their dynamic interdependencies [cf. 46, p 15]. This line of thinking should explore the role of reciprocal or circular causality [58; 59], or of recursive causality within an ensemble [3, p 130], as a process “in which the products or final effects *generate* their own *new beginning*” [ibid., p. 133; emphasis added], like in autocatalytic reactions [60, p 3], also to be viewed as an autocatalytic loop [61]. Thinking along these lines may lead to the concept of what has been called *holistic causality*, of a dynamic community [55, Ch. 8; 57, p 234; see also 62]. It may as well enable to envision a different conception of mind: “a conception of mind as a biologically emergent *ensemble* of powers of matter with irreducible *explanatory* principles of its own.” [25, p 135; emphasis added]. Consequently, one may think of the tremendous complexity of what may be called ‘mind-to-mind causation.’ [57, p 245] The development of mind may be defined, not strictly as individual development, but as one based on the unity of the ensemble or twosomes [6; 42; 8]. A view of development which may be linked with the notion of co-evolution; a view which takes “the evolution of animal *species* rather than embryonic development” as its starting point [10, p 99; emphasis added; see also 63, p 348; 11]. Development should, then, fundamentally be regarded as ‘an *active* adaptation to the environment.’ [10., p 100; see also 46, p 18] Such an adaptive process may be called a generative micro-evolutionary one for *each* of the partners: a process of minds evolving in their adaptivity through generativity in interaction. Taking a similar perspective, Barab & Kirshner [42] point to the dynamic generativity of knowing and learning which they see as basic for engendering what they call “explosive possibilities” for that learning. It is this promising complexity of interaction with its generativity which may account for the truth of the expression that, “in a real sense, two minds are better than one.” [19, p 89] It is the dynamic ensemble of two persons, of their communicative human interaction, which forms the unity, like in the drawing in Figure 1 of Escher’s “Whirlpools”. A dynamic unity which has no real separate inside and outside, but represents only one united path of development, like in the figure of Escher of the “Möbius Strip”, in figure 2 below. The ants seem to be at different sides of the path; in reality they are at the very same path.

Figure 2 Escher’s sketch of the Möbius Strip II

It is our strong conviction that rethinking of the mind and the seemingly simple concept of ‘interaction’ may offer not only a perspective of *liquefying* of reality but also of *complexifying* our mode of perceiving and experiencing reality in education which enables the transition of what Foucault has described as an “escape from the system of contemporary reality” [64]. An escape which may be called an escape from old ideas, which is, according to Keynes [20], the most difficult part of reinventing reality. The related question is if we are able to deal with the new complexity of reality [cf. 46, about harnessing complexity]. Do we have enough tools of complexity thinking to be able to do so in education? Can we become really explanatory about the complexity we may experience or are able to create in education?

Rethinking interaction

Interaction has been a concept with its own history in science. Although seemingly simple, in (educational) psychology it may be conceived as inherently complex [cf. 8, on communication]. That's why in different disciplines scholars are still waiting for an adequate theory of interaction, e.g. in the field of Cognitive Science, and Pedagogy: "What will a good (process) theory of interaction look like when it arrives." [65, p 590 ; see also 8, p 194; and 6]

It is my intention to focus on the complexity of the process of human interaction by taking that interaction as a generative process in which *not* information but influence is central [cf. 34, p. xii]. The modelling of interaction should therefore encompass the reciprocal influences each of the persons in interaction may have on the other: see figure 3 below.

Figure 3 Modelling interaction (I) as reciprocal (circular) causality in an ensemble of two persons with their reciprocal relationship or two (clusters of) latent variables

This figure can be read in two ways: as a couple of person A and person B and their interaction as reciprocal influences exerted on one another in time within a steady reciprocal relationship, or as two (clusters, or blocks of) latent variables within a causal framework exerting causal influences on one another. In practice, with all its complexity involved, these two representations may be regarded as intertwined! The two β 's are representative for the strength of influence one may have on the other at a certain moment. The two R's represent the relationship between the two partners or (clusters of) latent variables in interaction, which may be experienced differently by each of them, in terms of feelings of connectedness. The modelling of interaction has a quantitative representation as causal loops or cycles within the causal framework of Structural Equation Modelling (SEM), e.g. in LISREL [66]. The causal modelling of the interaction show a non-linearity of enhancement effects of reciprocal causality which is not very known in education science. These enhancement effects have been called self-enhanced loop effects by Hayduk [67; 68]. The books on causal modelling (e.g. in LISREL) are not very explicit about those effects and their meaning for modelling dynamic relationships in social sciences. The result of this is that the literature on this topic seems to keep a reality hidden which is fundamentally non-linear in its dynamic constituent elements. Yet, the results are a simple extension of the causal modelling of causal processes within reciprocal relationships. It demonstrates nicely the beauty of complexity by 'simple' modelling of interaction within reciprocal relationships (also called non-recursive relationships by Jöreskog and Sörbom, in [66]).

The formula's for the (different) total effects on A and B are difficult to find in literature. In Jörg [69] a full account of the modelling of reciprocal causality within reciprocal relationships has been given, including the formulas, with the two different β 's as parameters, of the total enhancement effects on A and on B. These formulas are given below (see [69] for the conditions in which these are valid).

Formulas of total enhancement effect (TE) on A and on B:

$$\begin{aligned} \text{TE on B} &= \beta_1 + [(\beta_1 * \beta_2) / (1 - \beta_1 * \beta_2)] * \beta_1 = \beta_1 + \Delta \beta_1 \\ \text{TE on A} &= \beta_2 + [(\beta_1 * \beta_2) / (1 - \beta_1 * \beta_2)] * \beta_2 = \beta_2 + \Delta \beta_2 \end{aligned}$$

The total enhancement effects are visualized graphically in figure 4 below. The causal process, with its reciprocal causal influences and its potential for non-linear enhancement effects has been described as self-reinforcing processes with its quantitative potentially non-linear total effects. The results show that the effects are *not* symmetrical! Modelling interaction this way, in terms of a process of reciprocal causal influencing, leaves the notion of a bounded system and of stable wholes behind [6, p 53; see also 3; and 58]. The interesting point, now, is how to link this kind of modelling of causal dynamics of interaction in terms of reciprocal causality or of recursive causality with the processes of *human* interaction. At first, we have to look carefully of how to describe interaction: in terms of verbal interaction with its implicit mediation [12], or as communication [37], as "the life and adventures of a couple of action and reaction" [7], or as communicative human interaction [7]. The view taken about human interaction is in full agreement with the view of Luhmann, who takes communication as "an emergent reality, a *self*-generated state of affairs." [8, p 157; emphasis added] To really understand the

Figure 4 Total enhancement effects on A and B, simultaneously represented in one figure because of symmetry of formulas (but effects do *not* need to be symmetric!)

complexity of such an emergent reality in what we prefer to call communicative human interaction, we have to open our eyes for “hitherto unknown generative mechanisms” [25, p 105], such as mechanisms of self-generative growth and the generative dynamics implied by these mechanisms [70; 18; see also 27, p 149, about self-generated fundamentals; and 71]. These generative mechanisms which are linked with complex responses are fundamentally causal of nature [(see 6; 7; cf. 3], and linked with the notion of time [72]. The introduction of the role of time is decisive in the modelling of causal interaction as sketched above.

Figure 5 Spirals of development as ‘loxodromic’ paths and their connection in a three-dimensional space

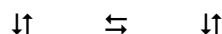
By taking Kantian notions of reciprocal causality, and so-called ‘transeunt’ influences seriously, we may develop a new general framework, fundamentally causal of nature, which may encompass human learning and development in terms of change and transformation, of qualitative shifts, of evolution, involution, and revolution, even of metamorphosis [12; 73; 3; see also 7, on Goethe and metamorphosis]. Such processes may lead to a spiral of development: a development which may take the form of a so-called ‘loxodromic’ path. This has been visualized in figure 5. The development of both A and B taken as personal development in time of an ensemble, of twosomes, may be regarded as a unity. Such a unity has been described, as we saw above, as a ‘cyclical-helical unity’ [31, p251]. The mechanism involved is a mechanism of *self*-enhancement, of auto-causality in an autocatalytic loop [61], via a process of reciprocal interaction with the other person involved in that interaction, leading to self-reinforcing processes, with non-linear enhancement-effects [74]. This kind of modelling shows clearly what may be called ‘the temporalization of complexity.’ [see 27] Interestingly it is not time itself but significant (basically humanly experienced or interpreted) *events* exerting influence and impelling force on the partner in interaction. It is similar to (fundamentally human) forces of interpenetration [see 54; see also 7, p 255]. It offers a very promising view of *humanizing determinism* in the ‘bootstrapping’ process of reciprocally influencing each other in time. One may describe the trajectory of non-linear development of the partners in human interaction in their interactive relationship [7, p 221] as a result of drawing energy from one’s neighbour (partner) in that interaction. It may be regarded as foundational of a new *humanistic* pedagogy as well [27, p 172; 75; cf. 24]. Such a pedagogy may have the potential to show the surprising efficiency of human interaction as a potentially deviation-amplifying causal process within the ensemble [see 16]. A link can be made with the evolutionary approach of adaptation by Sewall Wright, of adaptive landscapes with peaks of adaptivity [see 75, for a more elaborated sketch of the development of so-called ‘mindscapes’ and their dynamic interweaving]. It is the very generativity of interactive dynamics of humans in their interaction which may make the minds of individuals adaptive in their functioning. A sketch will be given of what may be called “an artisan human engineering view,” *not* a technological view, of how to ‘produce’ the adaptive ‘mindscapes’ of individuals interacting [22]. It is a view which takes the generative, the emergent phenomena of interaction seriously, but “*without steering* the participation in the interaction itself.” [see 27, p 245; cf. 24, p 199] For education it means ‘the end of certainty’, in a very fundamental sense [72; see also Dewey, in 24, p 129]. In Luhmann’s thinking it even implies a new kind of use of epistemology: one which is focused on analyzing the *uncertainty* of knowledge [27, p 152; emphasis added]. A question which becomes very important along this line of thinking in complexity is, if we can turn the complexity of a new Complex Generative Pedagogy into an *effective* pedagogy. May we really be able “to navigate the sea of uncertainty and of complexity” [77]?

Conclusion and discussion

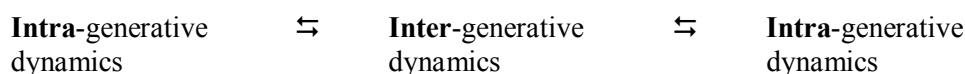
The modelling of (communicative) human interaction as causal interaction shows the process of reciprocal causation as a generative, time-dependent, and potentially non-linear process in time. The dynamics of this process corresponds with the causal dynamics of a self-reinforcing loop between latent variables in the causal framework of SEM (LISREL). It may be viewed, more generally, as a dynamic process of self-generating growth through a process of change and transformation which can be applied very well on the process of interactive learning. As such it may be viewed as a base for the foundation of a theory of causal interaction with its own methodology, a theory which shows the chances of the possible with its non-linear effects in time. It formalizes the seemingly unformalizable and extends thereby the limits of the reality as we know it from our experience.

The causal theory of interaction in (verbal, dialogical, conversational, and communicative) human interaction may be viewed as the answer to the question Bates et al. have put forward in their contribution to "A Compendium to Cognitive Science" [65; see also 6]: "What will a good theory of interaction look like when it arrives?" The 'answer' we have given above is not an easy answer. Actually it may be quite different from the traditionally expected, of a thinking that is based on the Newtonian paradigm of interaction as a sequence of action and reaction: the so-called billiard ball model of Newtonian science [59; 78; 59; 52]. So, it demands for a replacing of the old thinking [cf. 12, p 73]. Our approach of interaction indicates that a new framework should be called for, a framework which Juarrero (1999) describes as "one that *rethinks causality* in such a way as to provide some form of *ongoing self-cause*." [79, p 108; emphasis added] It encompasses a cyclical or circular type of causality [58, p 48], taking the cycle as a whole fundamentally dynamic unit of analysis. This (circular) type of causality, as we have sketched above, "*is a form of selfcause*." [79, p 5; italics in original]. As a theory of causal interaction it points the way toward a new understanding of cause and a different model of explanation [cf. 79]. As such it gives an answer to Vygotsky's general demand for an explanatory approach of (educational) psychology and the search for a (new) method in order to understand "*the uniquely human forms of psychological activity*." [12, p 65; italics in original] Our description of self-generative causality as a new method for the study of minds interacting, evolving in and through communicative human interaction in time, is fully in line with Vygotsky's demand that "*to study something means to study it in the process of change*." [12, p 65; italics in original] In line with his original thinking it requires that "*the method is **simultaneously** prerequisite and product, the tool and the result of the study*." [12, p 65; italics in original] Vygotsky's theoretical stance underlines what Blonsky (1921) already had stated before: "Behaviour can be understood only as the history of behaviour." [Blonsky, 1921, in 12, p 65] As a consequence we must rethink what, only at first sight, may *seem* natural: "even in very young children psychological processes are formed under the influence of verbal interaction with adults, and consequently are *not* 'natural'." [Leontiev, in 12, p 139; emphasis added]

The causal dynamics and generative mechanisms of change described above may be regarded as fundamental elements of the explanatory approach of human interaction which make the study of human learning a real science of that learning with two persons involved: of twosomes, or ensembles, developing in time within and through their reciprocal relationship. One may speak therefore about the reciprocal inter-dynamics between the two partners and the reciprocal intra-dynamics inside of each of the two partners. This may be presented symbolically as follows:



What actually happens is the dynamic interweaving of the two kinds of dynamics. Because we think these processes are generative, the representation of dynamics of processes may also be described in terms of the (causal) dynamics between generative processes:



It may be interpreted as the (causal) dynamic interweaving of two kinds of generative processes, co-evolving in time, with their potential non-linear effects developing in time, on the two persons (with

their networks or latent variables ‘inside’) involved in that interaction. It means that the whole of dynamic interweaving as a complex generative process is generative in nature as well. One may express the whole of the processes involved as ‘bootstrapping’ each other in the dynamic web of interweaving of the latent variables involved. It is not difficult to imagine the complexity of total effects this dynamic interweaving may have in time. This kind of interweaving also takes as serious the role of the partners as agents, as the weavers of the web they ‘weave’ in that complex process. The effects of the process, which have been called the Matthew and Comenius effects, are beneficial for both! The mechanisms of change are both autocatalytic and cross-catalytic in the processes of interweaving. The Matthew effect means simply that the more each of the partners ‘invest’ in the relationship, the more they may ‘earn’ of it in terms of their own development in time: something which is true for both! The Comenius effects shows that you may ‘earn’ of it by investing in the relationship, *even* when the partner is doing the same as usual! This is true for each of the partners separately. These peculiar characteristics of the hidden, generative mechanisms, which are similar to the re-entry mechanisms of the processes within the brain (and mind), are of utmost importance as results of the causal modelling shown above and elsewhere. But it means that it must always be taken into account that it is the partners who are giving the energy to this process, fuelling the process through their agency.

The modelling of the whole process of dynamic interweaving shows the causal mechanisms of change which leads to the processes of increasing complexification and potential transformation of the minds involved. It shows the causal dynamics and the enabling of qualitative transformations which Vygotsky (1978) described already in his main work ‘Mind in Society.’ [12] The whole of the processes involved may be conceived as ‘bootstrapping’ each other into Vygotskian spaces of near development: the spaces of possibilities and potential development. The non-linearity of these processes of ‘bootstrapping’ shows clearly the untapped potential of this kind of peer interaction within reciprocal relationships.

The final conclusion which can be drawn, based on our modelling of communicative human interaction, is that it is *not* possible to simply *apply* complexity theory to human interaction (see also [6]). It is the notion of circular, reciprocal causality with its inherent notion of reciprocal influencing as sketched above, which may be the very promising part of our new theory of humans in interaction, and of their minds dynamically evolving in time. It is time which is decisive in this process. It is the time to be given in education to (the building of) lasting relationships of dyads among peers which seems so promising. It may lead to notions like of Bruer (1993), that developing education along these lines of reciprocal human interaction, of reciprocal learning and/or reciprocal teaching, that we may foster “the educational equivalent of polio vaccine.” [80] *Not* by designing the generative process of interactivity, for this is not very well possible, but by having trust in the process of human interaction itself as a dynamic complex system, to be viewed as fundamentally autocatalytic and cross-catalytic, as self-perpetuating, self-patterning by the patterns of selectivity of the partners, and, most importantly, fundamentally self-enhancing in its effects. It is the phenomenon of hitherto unknown generative mechanisms, as inherent to the complexity of reality, which is decisive in this. John Holton has expressed the connection of interaction with reality very nicely: “So you have this interesting interaction where one is constructing a reality and the reality itself is constructing itself, really gets recursive like an Escher drawing.” [81]

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**5 Figures of Ton Jörg
below**

Figure 1

Sketch of M.C. Escher's 'Whirlpools' as connecting dynamic 'loxodromic' paths through interaction

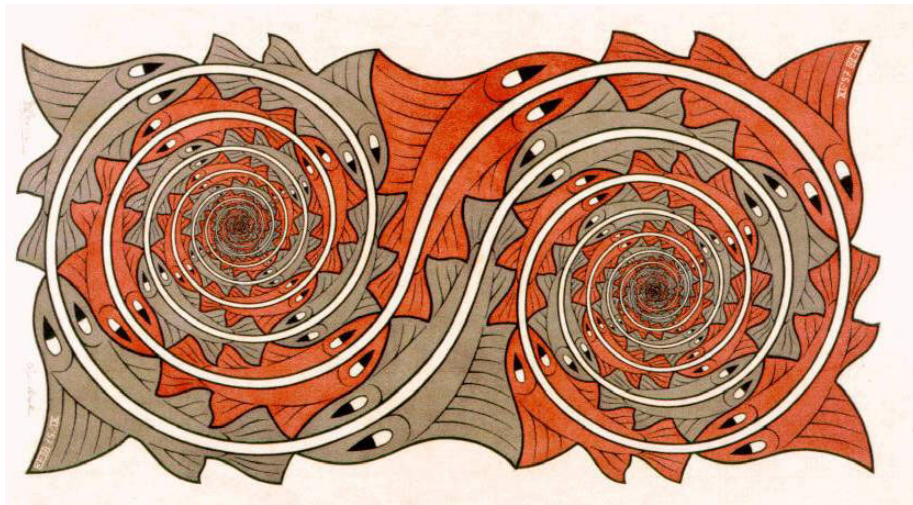


Figure 2 Modelling interaction (I) as reciprocal (circular) causality in an ensemble of two persons with their reciprocal relationship or two (clusters of) latent variables

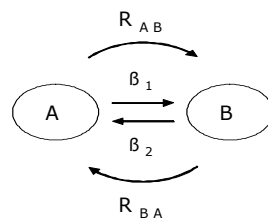


Figure 3 Escher's sketch of the Möbius Strip II

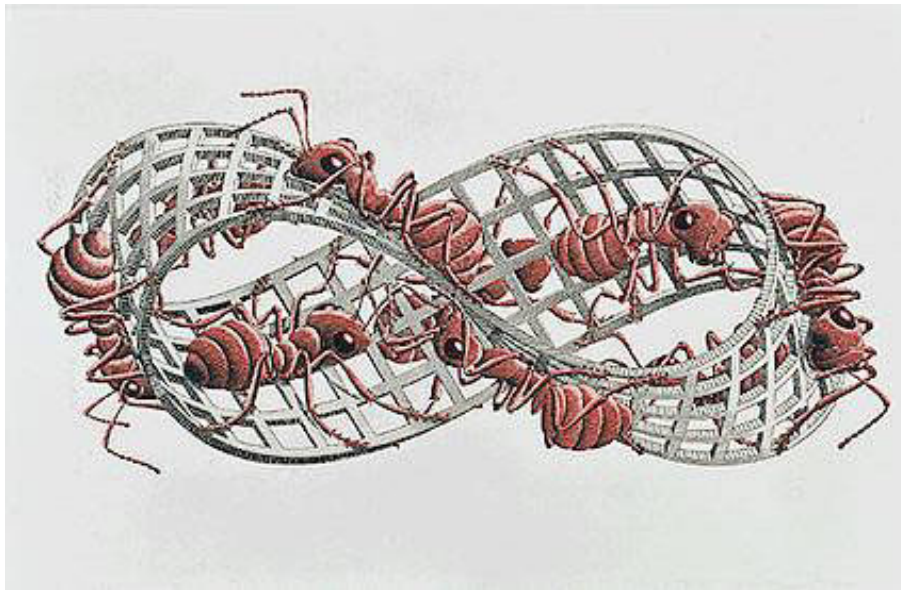


Figure 4 Total enhancement effects on A and B, simultaneously represented in one figure because of symmetry of formulas (but effects do *not* need to be symmetric!)

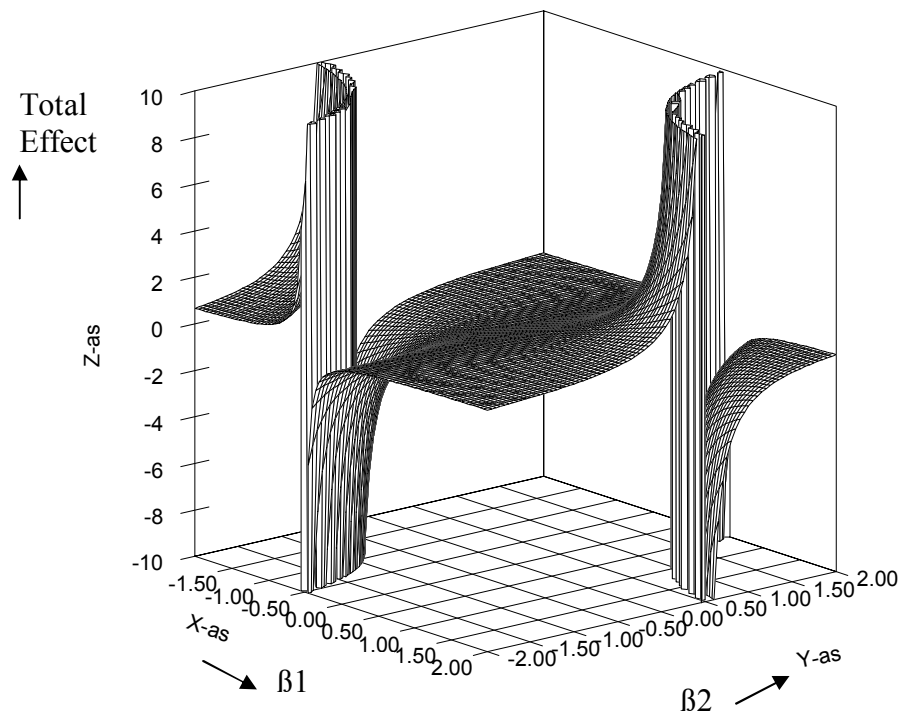


Figure 5 Spirals of development as 'loxodromic' paths and their connection in a three-dimensional space

