

On Reinventing Education in the Age of Complexity: A Vygotsky-inspired Generative Complexity Approach

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Reinventing education is the ultimate aim of this contribution. The approach taken is a radical new complexity-inspired bottom-up approach which shows complexity as the fount of creativity and innovation. Organizing complexity accordingly may be the foundation for a new complexified vision of education. It all starts with new thinking in complexity about how complexity is actually generated in the real world. Such thinking offers new kinds of complexity like generative and emergent complexity. The approach taken is very much inspired by the genius of Vygotsky, as a visitor from the future. His focus was not only process-oriented, but also very much possibility-oriented. His method was bottom-up, and opened new spaces of the possible, like the Zone of Proximal Development. Yet he was not able to deal with the problem of complexity in his days. He 'simply' lacked an adequate causal framework, which showed causation as a generative bottom-up process, to be linked with potential nonlinear effects over time. He could not explain what he saw as possible: the turning points and upheavals of learning and development. In this contribution the focus will be on the link between the new thinking in complexity and the causal, generative nature of complexity in the real world. This link may show the ontological creativity of the entire world in general, and of human learning and development in particular. It may show the power of generativity to unleash this creativity by a new way of theorizing on education. The complexity-inspired theory of development as generative change, as thriving on the generative power of interaction, is fundamental and foundational for this new theorizing.

The Russian scholar Lev Vygotsky has been recognized as a genius in his days (Wink & Putney, 2002, p. xvii), and later been described as “a visitor *from the future*” (Bruner, 1987). This is for good reasons, as will be shown below. His main focus was on learning and development of children. Yet, he has never been able to offer an adequate scientific view of the complex processes of learning and development (Vygotsky, 1978, Chapter 5). He has never been able to explain the deeply complex nature of the development he described so

eloquently. His problem of theorizing about the complexity involved in learning and development may now be recognized as “the *problem of complexity*” (see Cilliers, 1998; Morin, 2008). This is a deep problem that still dominates science and the science of complexity in our postmodern society (Cilliers, 1998). Scholars of our days may be described as (still) being “blind to the problem of complexity” (Morin, 2008, p. 6). This problem has been linked with the so-called ‘crisis of knowledge’ in the Age of Complexity (Cilliers, 1998, 2013; Jörg, 2014). The knowledge made available in our regular sciences has become the problem itself instead of the solution (cf. Müller-Prothmann, 2006). It may be recognized now that this crisis is still very much the *same* crisis, as described by Vygotsky in his days (see Vygotsky, 1978, 1997)! This crisis may be ascribed to the very same “problem of complexity” for the sciences, as described above.

So, it may be argued that this problem has largely remained unsolved since his days. The question is how this ‘failure’ of science in solving the crisis can be understood and explained? It may be argued it is because of the deep misunderstanding about the true nature of complexity. The misunderstanding that you can solve the problem of complexity by a top-down approach. Helga Nowotny (2003) seems very right in her analysis of the deep problem of concern here: that complexity seems still too complex to deal with by our sciences (p. 2). She has described this state of the art of studying complexity as “the embarrassment of complexity” for science in general:

When it dawns on us that the categories we *normally* use to neatly separate issues or problems *fall far short* of corresponding to the *real* world, with all its non-linear dynamical inter-linkages. (p. 1; emphasis added)

It may be understood from this view of the state of the art in science in general why the complexity perspective is “still very much under construction” (see Arthur, 2015, p.90), and not only for economics! It is no surprise, then, that Vygotsky, in his days, had serious problems to deal with the embarrassment of complexity, in developing an adequate scientific view of learning and development. His problems illustrate the deep problem of complexity for our sciences in general and for education in particular. This problem has not only a direct link with the question around the very possibility of education (Hansen, 2015) but also with the mission of this journal (see Davis et al., 2004; and Osberg, 2009).

Vygotsky’s Problem

In general, any fundamentally new approach to a scientific problem inevitably leads to new methods of investigation and analysis. (Vygotsky, 1978, p. 58)

Vygotsky described the ‘failing’ state of the art in science as a crisis in psychology (see Vygotsky, 1978, p. 5; and Vygotsky, 1997). Based on his analysis of the crisis, he showed a new direction for the social science, i. e. for psychology. Yet, in our view, he has not been able to offer an adequate explanatory framework for understanding the complexity of the causal dynamics of interaction involved in his main study of learning and development of children (Vygotsky, 1978, p. 73). Interestingly, he *was* convinced that thinking in complexes was very much needed to offer an adequate account of the causal dynamics of interaction (Vygotsky, 1978, p. 62). He noticed correctly that contemporary psychologists “were not interested in complex reactions as a process of development” (ibid., p. 68). He stressed in his description of the study of reactions, in terms of “the dynamic flow of the entire process of its development” (ibid., p. 69), that “the complex reactions must be studied as a *living process*”

(p. 69; emphasis added). Yet, he was not able to offer an adequate account of the nature of complexity involved in the living process; that is, as taking place within “the actual *causal-dynamic relations* that underlie phenomena” (ibid., p. 62; emphasis added). In his description of the process, Vygotsky was not able to link the dynamics of interaction with the nonlinear effects he described. He could not make the link between the *upheavals*, the *leaps* or *turning points* in child’s development, and the metamorphosis or the qualitative transformation brought about by the interaction among the participants in the very complex process of learning and development (see Vygotsky, 1978, p. 73). Vygotsky did not describe the role of the shaping forces and their (causal) effects on the participants involved in the causal dynamics of interaction. Effects which are linked to the *reciprocal* influences exerted by the actors *on each other*: operating causal *shaping forces*, evolving over time. Vygotsky’s central focus was on the development of the child as an individual, thriving on the interaction *with others* (cf. Follett, 1924/1971, for a different view).

In this contribution we will focus on the *true nature of complexity* involved in the interaction with others. The fundamental challenge is to *explain* the potential nonlinear effects of that interaction from a radical new complexity perspective. This is based on a new way of thinking in complexity (Jörg, 2011, 2016). Vygotsky was right that you cannot find such a new way of thinking; you have to invent it (see Vygotsky, 1997)! The true challenge, then, is one of *reinventing* science in the Age of Complexity (cf. Laughlin, 2005, for physics; and Arthur, 2015, for economics). This challenge is, in our view, very much the challenge for *reinventing education* in this Age of Complexity too!

The Age of Complexity

The Age of Complexity may be viewed as a radical new age, in which science is actually in a *transition phase* (see Nowotny, 2013, p. 2). The Age of Complexity may not only be linked to “*opening science*” (Wallerstein et al., 1996), but also to “*re-thinking science*” (Nowotny et al., 2001). It may even be linked to the possibility of “*reinventing science*” (Laughlin, 2005; cf. Arthur, 2015).

From a historical point of view, science may be viewed as being in a kind of *pre-paradigm* period (Kuhn, 1970), as being at the *edge* of a scientific revolution (Jörg, 2011, 2017). This revolution, we think, is about a new generative bottom-up approach, based on new thinking in complexity about the true *generative* nature of complexity. The transition involved is the transition of the Age of Reductionism into the Age of Complexity, to be viewed as an Age of Emergence (see Laughlin, 2005). The very generative nature of complexity may *open the possibility* to explain the very nature of generative emergence (Lichtenstein, 2014). All of this may have promising, unexpected, unanticipated effects for the field of education too. The transition shows the very promise of new thinking in complexity about learning and development as *fundamental nonlinear concepts*, as thriving on interaction with others (Vygotsky, 1978). This notion of learning and development as complex processes of interaction may open the *wondrous world of the possible* for education (see Jörg, 2016): *not as a risk*, but as a complex, deep *promise* of education (Hansen, 2015). That is, the promise of opening *new spaces of the possible*. Education may then be taken as being able to innovate itself. We may start to speak about the promise of complexity for education itself, in enabling complex, *generative* learning in *generative education*, as a way of open-ended, *bottom-up learning* (Johnson, 2001, p. 57; emphasis added). It opens “the question of education’s *possibility* and of its *realization* in life” (Hansen, 2015). This question is directly

linked with the possibility of “enlarging the spaces of possibility around what it means to educate and to be educated”, describing the mission of Complicity (Davis *et al.*, 2004). Opening and enlarging these spaces of possibility may be linked with the opening of very much *unexplored territories of complexity* for education. This implies the opening of the field of education with a new way of thinking in complexity about the complexity of education itself. It may also open the discussion about the possibility of education in the Age of Complexity (Jörg, 2009, 2016; Hansen, 2015).

A New Generative Complexity Approach

With our new approach of complexity, we may become able to reveal the *unexplored territories of complexity*. This may open a new world for the field of education: the world of the *possible*. First, we need to recognize that we are in a kind of so-called ‘pre-paradigm period’ (see Kuhn, 1970), with scholars of all kind, ‘waiting’ for a new science to arrive. A new science, which may be based on the new paradigm of *complexifying* (Morin, 2008). This new paradigm may open a new *generative* complexity approach for science (Jörg, 2011, 2016, 2017). This new approach may be conceived as a fundamental and foundational *bottom-up approach* (see Holland, 1995, 2014). We may need to start a new way of thinking, so to become able “to *reinvent* science from the bottom down” (Laughlin, 2005). This reinvention of science itself may bring with it the possibility of *reinventing education*, and to open “the space of education” (Hansen, 2015) for all. Opening this space as a “wondrous world of the possible” (Jörg, 2016) may be conceived as opening a future world of education.

The new paradigm of *complexifying* may open the *complex* world of new spaces of possibility: that is, a world of *unlimited* possibilities (Maturana, 1980). This is opening and enlarging the field of education. That is, the very *possibility* of education in the Age of Complexity: by “enlarging the spaces of the possible around what it means to educate and to be educated” (Davis *et al.*, 2004). It may be shown how a new complexity-inspired bottom-up approach may be foundational for opening the unexplored path of ‘*imagineering education*’ in the Age of Complexity (i.school, 2016), with imagineering as “a complexity-inspired design approach” (see Nijs, 2014). This approach may take into account the role of the so-called ‘adjacent possible’, all for the sake of opening the new spaces of learning and development. These new spaces may now be conceived as *generative* spaces, such as the ‘Zone of Generativity’ (Ball, 2009, 2012ab; Jörg, 2016), and the even more complex, multi-dimensional ‘Space of Generativity’ (Jörg, 2016). The aim here is to show a way to *open* these new complex spaces of generativity *for* education. This may be enabled through new thinking in complexity about the complex processes of dynamic interweaving within dynamic unities of learners and the dynamic processes of dyadic interaction (Jörg, 2011, 2016; Caporael *et al.*, 2014). These processes are thriving on the full *generative power of interaction* (see Bruner, 1996). The complex *nexus of interactions*, with their generative power, may now be linked with the complex *web of relationships*, operating as *catalysts of novelty and innovation* (see Goldstein *et al.*, 2010, p. 2). They may as well be viewed as catalysts for the nonlinear effects, described by Vygotsky (1978): effects like turning points and upheavals (p. 73).

Understanding the Dynamics of the Nexus of Interaction

Vygotsky faced the fundamental problem of understanding and explaining the “causal dynamics of interaction”, and of the nonlinear effects he described as actually *possible* (see

Chapter 5, in Vygotsky, 1978). In our view, he had great problems to make this link. He not only lacked an adequate causal framework to model his description of the causal dynamics of interaction as a complex process of *nonlinear* interaction. He also had problems to recognize and explain the very *generative* nature of the causal dynamics involved in the interaction. He had problems to *explain* the nonlinear nature of the (total) causal effects involved in the process of interaction. He did *not* describe the interaction as a process of reciprocal influencing with *dynamic interweaving*, taking place within a web of relationships, like others have done (see Mary Parker Follett, 1924/1971; and Bohm & Peat, 2000, p. 194). Follett (1924) actually faced the same complex problem as Vygotsky: of explaining the true nature of the causal dynamics of interaction. Follett fully recognized the need for what she described as “the functional theory of causation” (Follett, 1995, p. 53). This theory encompasses the process of *reciprocal* causation (see Arthur, 2015, p. 94), involved in the dynamic unit of reciprocity of interaction (Caporael et al., 2013). In the days of Follett and Vygotsky, no adequate causal framework was available. So, no calculus was available to account for the nonlinear effects of the causal dynamics of interaction. These effects are linked to the complex process of causation, taking place in the process of dynamic interweaving between the actors involved:

my *changing* activity is a response to an activity which is *also changing*; and the changes in my activity are in part *caused* by the changes in the activity of that to which *I am in relation* and *vice versa* (Follett, 1995, pp. 42-43; emphasis added).

To put it differently:

while I am behaving, the environment is changing *because of my behaving*, and my behaviour is a response to the new situation which I, in part, have *created* (ibid., p. 42; emphasis added).

So, Follett fully recognized not only the complexities involved in interaction, but also the opening of spaces of possibilities by the actors involved in the causal dynamics of interaction, as being *enabled* by the complex dynamic process of interweaving within relations.

To fully understand and *explain* the causality involved in the causal dynamics of interaction is a complex problem indeed (see Jörg, 2011, 2016, 2017). It is of importance to understand that, with the *science-as-we-know-it*, and the causal *framework-as-we-know-it*, it will *not* be possible to understand and explain the nonlinear effects of the causal dynamics of interaction (cf. Grotzer, 2012). It will not be possible to understand the complexity involved in causality: that is, of causation as a *generative* process (see Jörg, 2011, 2016, 2017). We need a new *generative* lens to see the new possibilities (Jörg, 2017).

The message to be derived from the above is that we urgently have to *learn* causality in a complex world (see Grotzer, 2012). We have to *learn* causality anew, as *complex causality*, involving forms of causality like *mutual* causality, *cyclic* causality, *relational* causality, and *spiral* causality (see Grotzer, 2012). All of these forms of causality actually describe what we are very much *missing* in understanding the complexity of causal dynamic interaction. We may then better understand why “we are running against the hard wall of complexity” (Barabasi, 2003, p. 6). In our view this is the main reason why “we are still blind to the *problem of complexity*” (see Morin, 2008, p. 6). We ‘simply’ have no tools and method to understand the very *generative nature* of causality and to understand causation as a fundamental *generative process*: as a process of *self-causation* (Jörg, 2011, p. 150; cf. Goldstein et al., 2010, p. 3). It may therefore be well understood that the framework of causality, like the

complexity perspective, is “still very much under construction” (Arthur, 2015, p. 90). It should be clear by now that we need a *new* causal framework about the causal dynamics of interaction. Only then we will become able to understand the true *generative, emergent* nature of complexity.

In regard to the state of the art in science, it seems to be the case that scholars of science are *not* missing what they are actually missing *most*: a new account of causality as *nonlinear causality* (Juarrero, 1999). They do not seem to *miss* a scientific account of causation as a (self-) *generative* process with potential nonlinear effects of strengthening over time. They actually do *not* seem to miss a causal framework of nonlinear causality, needed to account for a truly complex world: that is, a complexly *generative* world. This is a world with generative complexity, emergent complexity, of complexity as bootstrapping complexity, and of complexity as self-potentiating and self-sustaining (Jörg, 2017). A world with complexity, with systems operating with the complex capacity of *perpetually inventing themselves* (like economy; see Arthur, 2015, p. 25). It may be understood and should be understood that we urgently need new kinds of complexity, so to become able to offer a radically *altered* account of the very complexity of reality (cf. Kauffman, 2009, p. xv). The new kinds of complexity, linked with emergence, may “offer a key to new kinds of understanding” (Holland, 2014, p. 5): that is, of understanding the world as a complex *generative* world. A world in which “the interactions of interest are *nonlinear*” (ibid., p. 4; italics in original). A world in which so-called ‘bottom-up’ effects (ibid., p. 5) have their place, as a result of emergence, thriving on the full generative power of interaction. A new, much more complex world, showing a different kind of possibilities for education, in opening and enlarging the spaces of possibility *for* education, like the multi-dimensional Space of Generativity (Jörg, 2016, 2017). This new complex space may be taken to be a very complex concept, of relevance for education.

A Complex Causal Framework

Below, we will sketch a short overview of the complexity of causal dynamics of interaction (see Jörg, 2011 and 2016, for a more complete sketch of the framework). The causal dynamics is taking place in the interaction between two actors or entities, with their so-called ‘latent variables’ linked to them: see Figure 1 below for the simplest view of this interaction. This figure represents *mutual* causality, with interaction as mutual causal processes, which “is used in many disciplines” (Milsum, 1968, p. 23; see also Maruyama, 1968). The key in understanding the *causal* complexity involved in mutual causality is to be found in understanding the *generative* nature of causality and of causation as a generative process; that is, as being operative as *reciprocal causation* within reciprocal relationships between entities.

We may understand the unit of two entities involved in interaction as a so-called ‘*self-generative unity*’ (Jörg, 2017; cf. Whitehead, 1978, p. 47, on a ‘*self-creative unity*’). The change involved may be linked with “self-generating social change” (Maruyama, 1968, p. 96, in social and cultural evolution; cf. Keller, 1985, p. 132). It is important to understand the complex *dual* nature of the loop as a self-generative unity, with two entities / actors, and their *different* causal influences and their corresponding direct effects on each other. The interaction takes place within a reciprocal causal relationship, with the relationship between A and B being *different* from the relationship between B and A!

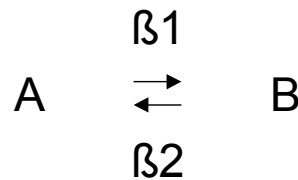


Figure 1. A structural model of causal interaction between so-called ‘latent variables’, with corresponding parameters of *direct* causal effects

Not only the *direct* causal effects on each other are different, but also the *total* causal effects on A and B. These total effects are composed of the *direct* causal effects, the *loop* effect, and the *indirect* effects (see Jörg, 2011, 2016). The *loop* effect may be described as a geometric series as follows:

$$\beta_1 * \beta_2 + (\beta_1 * \beta_2)^2 + (\beta_1 * \beta_2)^3 + \dots + (\beta_1 * \beta_2)^n$$

The geometric series may be re-described as:

$$(\beta_1 * \beta_2) / 1 - (\beta_1 * \beta_2).$$

This is the case if the absolute value of the product of $\beta_1 * \beta_2$ is smaller than the value 1 (see Jöreskog & Sörbom, 1993, p. 154). This loop effect may be conceived as a so-called ‘*multiplier effect*’ (see Milsum, 1968, p. 64; and Holland, 1998, 2014). The loop may be called a ‘*multiplier loop*’ (ibid., p. 64). The loop effect, as a multiplier effect, may increase over time in a *non-linear* way (ibid., p. 65), with increasing values of the two beta’s. The loop effect is actually the *key* for understanding the very *nonlinear nature of causality* and of reciprocal causation, with the corresponding potential non-linear effects over time. Emergent causality, in turn, may be taken to be the key for understanding complexity as *generated* over time: that is, for understanding *generative complexity* (Lichtenstein, 2014).

It is of importance to understand that the *total* effects on A and B are actually *generated* in and through the “causal dynamics of interaction” (Vygotsky, 1978). The functions of the total effects may be understood as *generative functions*, descriptive of how causal effects on A and B are actually *generated* in the complex process of reciprocal causation. These functions may *also* be understood as so-called ‘*transition functions*’, descriptive of future possibilities and states of A and B as complex entities (cf. Holland, 1998, p. 128). The *total* causal effects on A and B may now be understood as *emergent effects*, *generated* over time, being descriptive of “transitions from state to state” (Holland, 1998, p. 128). The underlying dynamics can be viewed as generative *emergent* dynamics. The formulae of the total causal effects of the causal dynamics of interaction may be viewed as expressing “a new kind of law” (Kauffman, 2013, p. 188): a law expressing the *dual* potential nonlinear effects of the causal dynamics of interaction. This law may *explain* what Kauffman describes as “the *emergence of complexity*” (ibid., p. 188; emphasis added). This law may now be called “the *Causal Law of Emergence*” (cf. Kauffman, 2013, p. 188; emphasis added). It actually describes the *dual* effects of the causal dynamics of interaction. This new law may finally explain *how complexity is actually generated in a complex world*: as operating in a dynamic network of interconnected (causal) loops. From this conclusion, we may also understand why “[T]he complexities introduced by *loops* have so far *resisted* most attempts at analysis” (Holland, 2014, p. 39; emphasis added).

We may also understand why “we don’t understand the behaviour of cyclic neural networks very well” (Holland, 1998, pp. 20-21).

The complexity of the causal effects within *cyclic* networks, operating through multiplier effects, may be viewed as the fundamental and foundational *key* for connecting *causal* complexity with the new kinds of complexity, like generative, emergent complexity in dynamic networks of interconnected loops. *This is opening new spaces of the possible within unknown territories of complexity, hitherto still very much unexplored.* This may finally “reveal a new world” (Arthur, 2015, p. 25): *also* for the field of education!

With the Causal Law of Emergence, described above, we can finally *explain how causal complexity may develop into generative, emergent complexity* in this complex world. This strongly supports Holland’s conclusion that “*generated complexity is essential to emergence*” (Holland, 1998, p. 76; emphasis added). We think he is right in his view that “we will have to look at it closely if we are to *understand emergence*” (ibid., p. 76; emphasis added). His view about the very *generation* of complexity from simple specifications is daunting indeed “because it assures that complexity will be pervasive in the world around us” (ibid., p. 76).

It may be concluded that the new framework of causality opens up a new way of *explaining* complexity in the real world, being operative as a complex *generative* world. It may also show how complexity can operate bottom-up in this *generative* world: through the generative emergent dynamics of causal interaction within reciprocal relationships. This complex dynamics is operating as emergent causality in the causal dynamics of interaction. This complex dynamics may now operate as deviation-*amplifying* dynamics (Maruyama, 1963; Jörg, 2011). The underlying mechanisms are very much *generative*, amplifying mechanisms. They are foundational for the conception of a *new theory of generative change* for education (cf. Ball, 2009), which is opening new spaces of possibility, with unexpected and unanticipated nonlinear effects over time. The theory of generative change may now be understood as a complexity theory of emergence: that is, a theory of ‘*generative emergence*’ (Lichtenstein, 2014). We may finally learn to use a *generative* lens to see the generative emergence, being operative in the real world as a generative world, enabled through generative change, and thriving on the generative process of causation, with its emergent causal effects.

Multiplier Effects

Interestingly the *direct* causal effects on A and B in Figure 1, which may have different values between 0 and 1, may take place in the interaction *simultaneously* (cf. Grotzer, 2012). The loop effect, however, is symmetric and the *same* for A and B! The loop effect may be described as a so-called ‘*multiplier effect*’ (see Holland, 1995, p. 25; and Holland, 2014, p. 68). The total effects, however, encompassing the symmetric loop effect, are *not* symmetric! It may be concluded that the loop effect and the total effects show an *unexpected* complexity. A and B may actually strengthen the total effects *on each other*, by increasing the direct effect on the other. The *result* of this increase may be understood as a complex, *generative* process. This describes the complexity of the generative change involved in the causal dynamics of interaction. This notion of complex, *generative* change can be linked to complexity as linked to a web of interactions “*bootstrapping* itself upward over time” (Arthur, 2015, p. 146; emphasis added). This complex process of bootstrapping may be taken to be the key for understanding complex processes of “bootstrapping each other” in interaction (Bruner, 1996,

p. 21). This effect corresponds with the so-called 'Matthew effect': "the rich get richer and the poor get poorer" (see Jörg, 2009, 2016).

It may as well be shown that A and B may also strengthen the total causal effects *on themselves* over time: by *increasing* the causal influence and the corresponding causal effect *on the other*. This may happen *even* if the direct influence of the other actor / entity on themselves keeps *constant* (see Jörg, 2011, 2016)! This effect may be conceived as the 'Comenius effect': "he who teaches others, teaches himself (see Gartner *et al.*, 1971, pp. 14-15; Jörg, 2016). This effect may be conceived as a process of so-called "self-bootstrapping" (see Arthur, 2015, p. 155). This process of self-bootstrapping may be linked to the emergence of a system or entity like the child as a complex learner "learning to program itself" (Arthur, 2015, p. 155). This notion can easily be linked to Vygotsky's view of the child becoming the master of his / her own learning and development (see Vygotsky, 1978, pp. 51, 73).

The simple model, sketched above, of the causal dynamics of interaction between two actors / entities, operating as *reciprocal causation* within their reciprocal relationship, may illustrate the *unexpected* complexity of nonlinear (total) effects of interaction, with the multiplier effects involved.

It may be concluded that generative emergent complexity can be grounded in causal complexity, operating as *nonlinear* causality within loops; that is, operating within the unit of two entities in interaction, to be conceived as a *self-generative* unity (Jörg, 2017). This conclusion strongly supports the view of Grotzer (2012): that we have to *learn* causality in a *complex* world. Causality and causation shows to be much more complex than scholars of all kind have assumed in the history of science.

We may finally become able to learn causality and causation as being part of a new "bottom-up paradigm" (Johnson, 2001, p. 67). We may learn a "bottom-up style of thinking" (Axelrod & Cohen, 1999, p. 29), as a new *mode* of thinking (*ibid.*, p. 28), so to become able to understand the unexpected, complex processes of change as complex, *generative* change. We may learn causality in a complex world, to become able to *learn* how emergence may actually operate in the *real* world (Arthur, 2015, p. 155), thriving on the causal dynamics of interaction as a complex, *generative* process of causation. We may finally learn how generative emergent complexity may be embedded and operate in a world which is "fundamentally different from that which has previously characterized modern science, with its emphasis on prediction and control" (Solé & Goodwin, 2000, p. 28).

Based on the new understanding of generative, emergent complexity, we may understand learning and development anew, being operative in a complex, *generative* world. A world which has remained very much *unknown*, also for those involved in theorizing on development and education.

Understanding Learning and Development Anew

Vygotsky's conception of development is *at the same time* a theory of education.
(Bruner, 1962, p. v; emphasis added)

The causal dynamics, described above, may now be linked to the causal dynamics of interaction involved in learning and development, as sketched by Vygotsky. This may include the potential nonlinear effects as conditional for effects such as turning points, upheavals, and qualitative transformation or metamorphosis (see Vygotsky, 1978, p. 73). The complexity involved may be viewed as evidence for the view that development plays a

special but *undertheorized* role in science (cf. Caporael *et al.*, 2014 p. 15). Not only in “accounts of biological evolution, cognition, and cultural change” (ibid., p. 15), but *also* in accounts of development in the field of education. It may be understood by now *why* Vygotsky had a hard problem to *explain* “the highly complex relations between developmental and learning processes” as complex *dynamic* relations (Vygotsky, 1978, p. 91). This problem may be recognized as the *hard problem of complexity* (cf. Barabási, 2003, p. 6). It is the problem of linking the effects of learning on the development of children with *nonlinear* effects. This problem is still a hard problem for theorizing on development and education. According to Paul van Geert, it is still “*completely unclear* what teaching and *learning* entail if conceived *at the level of specific activities and processes*” (see Van Geert, 1994, pp. 247-248; emphasis added; cf. Vygotsky, 1978, p. 57).

The causal effects, linked to the description of nonlinear causality and causal emergence above, may be taken as foundational for a way of *re-describing* the description of nonlinear effects of learning and development. They are fundamental and foundational for a new theory of change: that is, of a so-called “theory of generative change” (Ball, 2009). A theory which Ball has linked with the complex concept of ‘Zone of Generativity’, derived from Vygotsky’s concept of the ‘Zone of Proximal Development’ (see Ball, 2009, 2012ab; cf. Bruner, 1996, p. 76, on children, *generating* the Zone of Proximal Development). We may now better understand the true nature of *generative* change by our new complexity perspective. Generative change may now be understood as enabled by the *self-enhanced* loop effects, being operative within the causal dynamics of interaction. These loop effects operate as *multiplier* effects, thriving on the multiplicative *generative* nature of causal interaction. This generative nature is opening for the description of the full generative power of interaction, being operative within the causal dynamics of interaction (cf. Bruner, 1996).

The new theory of *generative* change may now be linked to complex, *generative* processes of learning and development, thriving on interaction in both *intra-* and *inter-*personal processes (Vygotsky, 1978). The theory may as well be linked to the complex dynamic interweaving of these generative processes and their generative outcomes over time. These generative processes are thriving on the full *generative* power of interaction (Bruner, 1996). The total *causal* effects of this interaction may now be understood as emergent ‘*bottom-up*’ effects, generated in *non-linear* interactions (see Holland, 2014, pp. 4-5). These total causal effects, thriving on the non-linear nature of causal interaction, may now be linked in a new way to the known concept of ‘Zone of Proximal Development’ (ZPD), introduced by Vygotsky (1978, p. 84). This Zone may be viewed as descriptive of “*bottom-up* effects” (Holland, 2014, p. 5; cf. Johnson, 2001). Very much in line with this view, Vygotsky was of opinion that “an essential feature of learning is that it *creates* the zone of proximal development” (p. 90; emphasis added; see also Bruner, 1996, p. 76, on children *generating* their own ZPD). Vygotsky adds to this: “learning *awakens* a variety of internal developmental processes that are able to operate *only* when the child is *interacting* with people in his environment and *in cooperation with his peers*” (p. 90; emphasis added).

The renewed concept of the ZPD may thus be described as a (very) *complex* concept, to be linked to the concept of ‘the adjacent possible’ (Kauffman, 1993, 2003; see also Loreto *et al.*, 2017). Every change in the shaping causal forces exerted by the actors in interaction may trigger a *generative*, deviation-amplifying mechanism which may bring about *nonlinear* (total) *causal* effects on the actors involved. These effects take place *over* time, without being dependent *on* time as a variable. These effects are a *result* of their interaction over time, taking place within their mutual, dynamic reciprocal relationship (Jörg, 2011, 2016). The

corresponding mutual effects of the causal dynamics of interaction may also be linked to so-called ‘*multiplier effects*’ of this interaction (Holland, 1998, 2014; Jörg, 2011, 2016). From this complex notion, we may better understand Vygotsky’s theory: that it is *through interaction with others*, through cooperation with others and with peers, that we may develop into ourselves (see Vygotsky, 1978, p. 90): that is by opening and enlarging new spaces of possibility, like the Zone of Generativity and the Space of Generativity.

Opening New Spaces of Possibility *for* Education

From the nonlinear effects of causal interaction within dynamic loops and the corresponding multiplier effects, we can now make a link with the concept of ‘generativity’ as a complex *network-concept*. We may conceive of generativity as thriving on the connectivity and interactivity of the network of dynamic, interconnected loops involved (Jörg, 2017). This description of generativity may show the power of generativity to *generate* the nonlinear multiplier effects: that is, through *non-linear interactions* within networks of dynamic, interconnected (causal) loops (cf. Holland, 2014). This is enabling for viewing generativity as a complex, *multi-dimensional* concept, to be linked with this *self-generative* unity. A concept which may be understood as closely connected to the concept of *creativity* (cf. Whitehead, 1978, p. 47, on the ‘*self-creative* unity’). This is opening for a new way of thinking, of thinking in complexity, about the opening of new spaces of possibility, like the Zone of Generativity and the even more complex, multi-dimensional Space of Generativity. These new spaces may now be taken as complex *generative* spaces of *possibilities* for education (see Fels, 2004, p. 76). Interestingly, the concept of ‘generativity’, originally conceived by the psychologist Erik Erickson (1950; see Bushe, 2013), has recently been described:

- as the power to *create* (Stepper, 2014, p. 1)
- the power that brings individuals into being [and] in great part sustains them without their choice or deliberate effort (Sassone, 1996, p. 519)
- the power of constituting the individual directed by that individual to becoming a being in-and-for-self (ibid., p. 519)

We may derive from this description that generativity can be linked to creative forces and power. The complex *creative* power of generativity may now be understood as thriving on the complex generative power of interaction between learners, with generativity itself conceived in a complex way, as being about

- the *processes and capacities* that help people see old things in *new ways* (Bushe, 2013, p. 2; emphasis added)
- the *cause and effect* of individualization (Sassone, 1996, p. 519; emphasis added)
- self-sustaining (Stepper, 2014, p. 2)

The creative, generative power of generativity may now be understood as the *complex, generative motor* of generative change. A generative motor which is operative in the complex generative dynamics of dynamic interweaving of learners and the corresponding *intra-personal* and *inter-personal* processes of these learners in their interaction (see Vygotsky, 1978; and Follett, 1924, 1995). These processes may now be taken as being “*both inter-individual and intra-individual processes*” (Sassone, 2002, p. 122). The learners are not only entities or agents being involved in a complex process of *inter-action*, but also as entities-in-process themselves, as a complex process of *intra-action*. This makes the whole dynamic unit so dynamic and unexpectedly complex indeed (cf. van Geert, 1994), also in the description of

the complex, dual effects on both learners in their interaction over time. We may now start to think in a different way about theorizing education, by questioning education anew, in terms of education's possibility (see Hansen, 2015). This may show the very complexity of education in the Age of Complexity. The hard problem of complexity, then, can be linked to the hard problem of education *itself*.

On the Question of Education's Possibility

the greatest and most difficult problem to which man can devote himself
is the problem of education (Kant, in *On Education*, 2003 / [1899], p. 11)

Kant was of opinion that the problem of education is a hard problem indeed (see quote above). More recently, David Hansen has put the fundamental question about education in terms of "the *possibility* of education" (Hansen, 2015; emphasis added). This question has a direct link with the mission of this journal, formulated in 2004, at the start of this journal: "to enlarge the spaces of *possibility* around what it means to *educate* and *be educated*" (Davis *et al.*, 2004; emphasis added). Questioning the very *possibility* of education may be taken to be a deep underlying problem for education itself! So, the question is still very much open, still waiting for an answer. The challenge that faces us in the Age of Complexity is to *re-think* education, with the possibility of "a transformation of education" (Nilsook *et al.*, 2014, p. 17). This possibility may ultimately lead to the possibility of *reinventing* education "from the bottom down" (cf. Laughlin, 2005, on physics)!

To answer the question of education's possibility, and the possibility of *reinventing* education in the Age of Complexity, we need to think about a new complexity perspective (cf. Arthur, 2015, p. 90). We want to argue here that we may find the answer in the new concepts of 'generative complexity' and of 'emergent complexity' (Jörg, 2011, 2017). These new concepts may describe "the *enhancement* of complexity as a fact of life" (Rescher, 1998, p. 6; emphasis added). This enhancement may also become a fact of education: by *opening* education's possibility for the field of education itself. For sure, this demands for a new way of theorizing on complexity *and* on education: that is on the complexity of *education itself*. This theorizing may have consequences for *organizing complexity* in education as the fount of creativity, thriving on the full generative power of interaction. This new theorizing may open new spaces of possibility for education, like the Zone of Generativity, and the Space of Generativity. Inspired by Vygotsky's view on learning and development through interaction with others, we should find ways to *handle* interaction (cf. Arthur, 2015). All of this new theorizing on complexity puts the very *possibility* of education in a fundamental new perspective in the Age of Complexity. The world of education may actually be turned into a *different* world: that is, a complexly *generative* world. We need a new lens, a *generative* lens (see Wink & Putney, 2002, p. 11, on the vision of Vygotsky). We need new theorizing, both on development and of education. We may see new, unexpected and unanticipated possibilities by looking at the world in new way (cf. Laughlin, 2005, for physics). In our view this is the true challenge for education in the Age of Complexity.

We urgently need a different, *much more complex* description of learning and development *for* education. For sure we need our imagination for that. With the help of Einstein's insight in the role of imagination, we should become aware that "[I]magination is more important than knowledge. For knowledge is limited to all we know, while imagination embraces the entire world" (in Nilsook *et al.*, 2014, p. 14). So, we need to start theorizing education, opening the possibility of *re-describing* our description of education by

the use of our imagination. The challenge for education, then, may be best described as “*Imagineering* education” (i.school, 2016), as a way to ‘solve’ the hard problem of education in the Age of Complexity. For sure, this will not be easy. We urgently need our imagination to reveal a new world of education for the future of education. The true challenge is to reveal a new wondrous world of the possible world for education: that is, a complex world of unexpected possibilities (Jörg, 2016, 2017). Of course, this is a hard and complex problem. The complexity perspective itself is also still very much under construction (Arthur, 2015, p. 90; see also Barabási, 2003).

A New World for Education?

Nobody knows what the adjacent possible space looks like and even conceptually it is *not clear* which tools one could possibly adopt to chart it (Loreto *et al.*, 2017, p. 79; emphasis added)

Thinking about the very *possibility* of education from a new complexity perspective, with a new vision of complexity as generative, emergent complexity, may be of help “to reveal a new world” for education. Henceforth we may think of education in a radical new way: as taking place through a discursive practice and dynamic process of interaction and of dynamic interweaving within web-like units, like the dyadic self-generative unity. That is, a discursive practice “that reveals the structure and contents of individual’s lives to themselves” (Sassone, 1996, p. 516). The dynamics of interweaving may be taken as a very complex process, thriving on the interaction within relations with others (Vygotsky, 1978). The complex, *generative* processes of becoming, thriving on the generative power of interaction, may then be viewed as fostering “the *emergence* of a self-observational mediating self for each individual” (Sassone, 1996, p. 516; emphasis added). Based on this complex view, we may better understand the *power of generativity* as a kind of complex, creative power, being operative in the processes of coming *into* being *through* complex generative processes of becoming.

Based on Sassone’s understanding of the complex processes involved in development, we may now become able to understand the very generative, emergent complexity involved in Sassone’s description of development, in terms of “one *makes* oneself *through* one’s generativity” (ibid., p. 520; emphasis added). This complex process is enabled through the complex power of generativity. A power which is thriving on the full generative power of interaction within relations with others (Vygotsky, 1978). This creative, generative power of generativity is opening for a fundamental *re*-description of education: of what it means to educate and to be educated. A *re*-description which is opening for a radical *reinvention* of education. This reinvention of education may be linked with the enlarging and the opening of new spaces of possibility. The enlarging of these spaces may also be linked with the concept of “a dynamic *generative* space of *possibilities*” (Fels, 2004, p. 76; emphasis added). These generative spaces can be linked with the complex concept of the ‘Space of Generativity’ (SoG). This may be done by linking the ‘space of interaction’ (Fels, 2004, p. 80) with the so-called ‘adjacent possible space’ (Loreto *et al.*, 2017, p. 79). Interestingly, Loreto *et al.* are of opinion that “[N]obody knows what the adjacent possible space looks like” (p. 79). These authors are convinced that “it is not clear which tools one could possibly adopt to chart it” (ibid., p. 79). They describe the need for “a deeper understanding of the different nature of *triggering* events along with the signatures of the adjacent possible at the *individual* and *collective* level” (ibid., p. 79; emphasis added).

All of the changes, described above, may be conceived as opening radical new ways of thinking in complexity about *education's possibility itself* (Hansen, 2015). It shows the deep link between theorizing development and theorizing education (cf. Vygotsky's view above). This new way of thinking is bottom-up, being an essential part of the new paradigm of complexifying. The effects of the interaction within the space of interaction may show for instance the possibility of 'generative emergence' (Lichtenstein, 2014). The space of interaction may then be taken to be triggering *complex generative spaces of possibilities*, enabled through interaction. The opening and enlarging of these spaces is thriving on the full generative power of interaction. The most important challenge for education in practice, then, is to *create* these spaces as new spaces of opportunity for learners. The new Spaces of Generativity (SoG) may show the *unanticipated possibilities and potentialities* for learners: of learners *bootstrapping each other upward* into their individual SoG (cf. Bruner, 1996). Such bootstrapping may show the potential increase of generativity as a very complex capability of learners: of *knowing how to go on* (see Lord, 1994)

The new description of education may show the very possibility of *enlargement* of the cognitive domain as *unlimited* (see Maturana, 1980, p. 38). This *unlimited possibility of enlargement* as an *un-anticipated*, very complex possibility for education, is possible through the complex, generative, emergent processes of coming into being through *generative, emergent* processes of *becoming*. This complex possibility for education can be linked with Maturana's description of the dynamics of interaction:

We can say that *every internal interaction changes us* because it modifies our internal *state*, changing our posture from which we enter into a *new* interaction (Maturana, 1980, p. 39; emphasis added).

This *new* interaction, in turn, takes place in *new* relations:

As a result new relations are necessarily *created* in each interaction and, embodied in new *states* of activity, we interact with them in a process that repeats itself as a historical and *unlimited transformation* (ibid., p. 39; emphasis added).

This description of dynamic interweaving, thriving on interaction within *created* relations, may show in what way a theory of development may be taken as a theory of education, as inspired by Vygotsky's way of theorizing (Bruner, 1962). A new theory, to be based on a new theory of generative change, thriving on the generative power of interaction within relations with peers. A theory which may ultimately lead to the *transformation* of education. We go deeper into this below. First, we want to make the link with Vygotsky's way of thinking as a fundamental bottom-up style of thinking (cf. Axelrod & Cohen, 1999, p. 29).

The Position of Vygotsky

From the above *re-description* of education, we may better understand Vygotsky's position about learning and development (L&D). A position which is based on interaction within relations with the other. Vygotsky was of opinion that it is through interaction with others that we develop into ourselves. The development is taking place within the ZPD as a *created* space, as a *result* of learning *in* and *through* that interaction. Although Vygotsky conceived of nonlinear phenomena like turning points, upheavals etc., he did *not* describe *how* the mechanisms and dynamics involved were actually being 'at work' in the interaction. Yet, he was convinced of the need to take a radical different approach of learning and development,

by adopting a radical different *method* (see Vygotsky, 1978, Chapter 5). His method was inspired by Wundt's description of the complex role of stimuli "that *generate* a change in the psychological process linked to them" (Vygotsky, 1978, p. 59; emphasis added). Vygotsky's method may *in general* be described as a way of analysis focusing on:

- The *process* instead of the object;
 - *Explanation* versus description; and
 - *Dynamic analysis* of development that *returns* to the source
- (in Vygotsky, 1978, pp. 61-65; all emphasis added).

The result of the corresponding *dynamic analysis* of development will be "a *qualitatively new form that appears in the process of development*" (ibid., p. 65; emphasis added; cf. Fels, 2004, p. 79). Vygotsky's description of his method of analysis of development shows the main characteristics of the new science of complexity, advocated in Jörg (2011, 2016, 2017).

Vygotsky actually wanted to *invent* a new science as a response to the state of the art in his days, but, although he clearly saw the importance of interaction for L&D, he did not recognize the generative nature of the dynamics of interaction, operating within the scaffolding generative relationships involved in that interaction. He did not describe very well *how* to foster L&D and the nonlinear effects of interaction, described by him (Vygotsky, 1978, p. 73). In his description of method he did not link the causal dynamics with an adequate framework of causality: a framework which could show the very *nonlinear* nature of causality operating in the complexity of the causal *nonlinear dynamics* of interaction. This demands for a *new way of thinking* about causality and of causation. The causal dynamics to be conceived from a new complexity perspective may involve "self-generated enhancement" (Holland, 1998, p. 13; emphasis added), enabled through *self-enhanced* causal loop effects, and the presence of *spiralling* causality (Grotzer, 2012). These effects are being operative in the developmental processes, proceeding in a spiral: "passing though the same point at each new revolution while advancing to a higher level" (Vygotsky, 1978, p. 56). Based on this new understanding of spiral development, enabled through the causal, generative dynamics of interaction, being operative within the interpersonal reciprocal relationships, it may be understood that "[A]ll the higher functions *originate* as actual *relations* between human individuals" (ibid., p. 57; emphasis added). Vygotsky's description gets close to the complex, dynamic process of interweaving within a dyadic unit, described above.

New Mode of Thinking

The new ways of thinking *in* complexity *about* the new kinds of complexity, sketched above, may be taken as foundational for a new way of thinking about the mission of education in the Age of Complexity. This will be opening up the unexpected possibility of *reinventing* education from the bottom down (cf. Laughlin, 2005, for physics; Holland, 1998; Johnson, 2001; and Arthur, 2015, for economy). This reinvention of education may be based on a new generative bottom-up approach of complexity, with corresponding 'bottom-up effects' (Holland, 2014, p. 5), like the self-enhanced loop effects (see above), enabled through *self-generated* enhancement (cf. Holland, 1998, p. 13). These bottom-up effects are potentially nonlinear over time (see above). The new generative bottom-up approach may be based on the paradigm of complexifying, to be taken as a new fundamental and foundational "bottom-up paradigm" as one, which is beginning to emerge (Johnson, 2011, p. 67; and Kelly *et al.*, 2016, p. 52). This new approach *replaces* the top-down approach still dominating the

science-as-we-know-it. Living in the Age of Complexity, time has come to *replace* the Age of Reductionism into the Age of Complexity, to be taken as the Age of Emergence (Laughlin, 2005). This age may now be viewed as the Age of *Generative* Emergence (cf. Lichtenstein, 2014). The complexity of generative emergence can be based on a *new theory of generative change*. This theory may be based on the complex, generative model of causal dynamics of interaction within relations, sketched above and elsewhere (Jörg, 2009, 2011, 2016). The theory of generative change is very much *possibility-oriented*, based on a process-oriented approach of learning and development. This theory and approach may be derived from Vygotsky's radical approach of dynamic analysis as his method, being fundamentally *process-oriented, bottom-up* and *explanatory*, so "to reveal the actual causal-dynamic relations that underlie phenomena" (Vygotsky, 1978, p. 62). These are phenomena like turning points, upheavals, leaps, and qualitative transformation or metamorphosis (ibid., p. 73). These phenomena may now be viewed as linked to the bottom-up behaviour of learners in interaction, enabled by the bottom-up effects of that interaction.

Vygotsky's focus was clearly on "the *dynamic flow of the entire process of development*" (ibid., p. 69; emphasis added). Although he had an open eye for the complexity involved in the very complex processes of learning and development, he shows in his work no recognition of the truly complex nature of the causal dynamics involved in the interaction within relations with peers. He did not describe the complexly *generative* nature of the dynamics, or the dynamic generative spaces of possibility involved (cf. Fels, 2004, p. 76). Yet, and most importantly, he *did* recognize very well that you 'simply' cannot explain the complexities involved from a top-down approach of science (cf. Waldrop, 1992, pp. 278-280). He knew very well that a radical *new mode of thinking* was needed: one, which starts from a bottom-up approach, to be taken as both *process-oriented* and *possibility-oriented*. An approach which may *replace* the dominant *ends-oriented* approach in education. An approach which is opening the future of education in the Age of Complexity, by opening new spaces of possibility, like the ZoG and SoG, as new generative spaces *for* education. An approach which shows how learners may achieve individual and collective generativity: by *co-creating* these spaces *both* for themselves *and* for the other. They may also *generate* their own learning and development *within* their SoG, through complex processes of generative change within the self-generative unit of dyadic interaction. The aim of these *generative* bottom-up processes is to achieve the complex capability of generativity within their own SoG: that is, the complex capability of "knowing *how* to go on" (Lord, 1994). This complex capability of learners, with their evolving identity, involves the question "what is this learner able to *do* and to *be*?" (Nussbaum, 2012, p. 204). Learners, then, achieving their personal identity, may be viewed as dynamic generative processes: of "knowing is *doing* is *being*" (Davis, 2004, p. 154; emphasis added). Their identity may as well be viewed as embodied in the *inter-activities* of dynamic forms of *inter-action*, thriving on the connectivity of these forms (cf. Davis, 2004, p. 154). The internal capabilities of the person, generated within these dynamic forms can be taken as *complex states of the person*, which are *fluid* and *dynamic* (Nussbaum, 2012, p. 21; emphasis added). The complex multi-dimensional concept of 'generativity' may now be taken as representing the "*combined (internal) capabilities*" (p. 21; italics in original) of the person. Generativity, then, may be viewed as the *complex generative motor* of development: that is, the *generative* motor which enables the *generation* of complex, fluid, and dynamic states of being in learners as inherently complex human beings. This is truly opening new spaces of possibility for understanding education anew. That is, for opening the very *possibility* of education in the Age of Complexity.

The link between theorizing education and theorizing development shows the very *diversity* of education's possibility: around what it means to educate and to be educated. This may show the unexpected and unanticipated possibilities of *rethinking* education. It may even show the unexpected and unanticipated possibility of *reinventing* education, and for the reinvention of schools (Darling-Hammond *et al.*, 2016). Of course this may also have deep implications for the mission of education.

The Mission of Education in the Age of Complexity

All of the new thinking in complexity about the true nature of complexity, the possibility of education, and the possibility of rethinking and reinventing education, may bring us back to the basic question, about the very *mission* of education, about "what it means to educate and to be educated?" (Davis *et al.* (2004). We may now find an answer to that question from a complexified vision of complexity, based on the new paradigm of complexifying, to be taken as a complex bottom-up paradigm.

Learning and development (L&D), as linked to interaction, may show to be inherently complex processes, showing complexities which have remained very much unknown. This demonstrates that the concept of 'development' is still very much *under-theorised* (Caporael *et al.*, 2013, p. 15; cf. Nussbaum, 2012, p. 186). Because development is so closely linked to a theory of education (see Bruner, 1962, on Vygotsky's theorizing), this has serious consequences for education too. The theory of education-as-we-know-it may be viewed as a defective, incomplete theory (Nussbaum, 2012, p. 186). This theory may therefore be taken as *under-theorised* too! This theory 'simply' *cannot* afford the answer(s) to the question about the mission of education, posed by Davis *et al.* (2004). It cannot account for the complex multi-dimensional concept of 'generativity' as the complex, generative motor of development. It cannot account for the complex generative states of being of learners as actors in education. Henceforth, education should be taken to be *much more complex* than we always have *taken* it to be. We may take inspiration for the development of a new, (much) more complex theory of education by a new way of theorizing on development, as inspired by the work of Vygotsky. He described development as "the *growing complexity* of children's behaviour" (Vygotsky, 1978, p. 73). Vygotsky described the aim of L&D for children as "to *master their own behaviour*, at first by external means and later by *more complex inner operations*" (*ibid.*, p. 73; emphasis added). Yet, he was not able to *explain* the complexity involved in creating the ZPD by the child. He 'simply' lacked an adequate causal framework to do so.

The above description shows the complexity of what education may really be about in the Age of Complexity. This brings us to the more specific question "how to *design* education as opening the new Spaces of Generativity as being an essential part of a new possibility-oriented generative complexity approach?", and the question "how to facilitate the *unlimited enlargement of possibility* of the cognitive domain?" The answer to these questions may be found in a new approach, which may be described as "Imagineering education" (see Stanford University, 2014; and i.school, 2016). Imagineering education may be taken as a complexity-inspired design approach (Nijs, 2014). This is opening for a generative design of education.

The secret of the new design approach is in understanding how complexity may actually be 'at work' as generative, emergent complexity in complex processes of *generative learning*, enabling for so-called '*generative learning communities*' (Stacey, 2014, p. 3; emphasis added).

Mary Stacey is in our view very much right, in stating that “[T]he secret of *growing* a successful *generative learning community* is to *design it*” (ibid., p. 3; emphasis added). This demands, however, for new *principles of organization*: that is, of *generative* principles of organizing complexity. Principles, which are inclusive of self-organization (Cilliers, 1998, p. 103; cf. Johnson, 2001). According to Cilliers, we should be sensitive to “complex and *self-organizing interactions*” (p. 107; emphasis added). We also should “appreciate the play of patterns that *perpetually transforms the system itself as well as the environment* in which it operates” (ibid., p. 107; emphasis added; cf. Arthur, 2015, p. 25).

The above description of the link between complexity and education may lead to a deeper questioning of what is needed to conceive of the *possibility of education* in the Age of Complexity. This questioning may ultimately lead to the possibility of *reinventing* education. What is urgently needed is a way of complexifying our theorizing on education: by *complexifying* our theorizing of development. What is needed is a new *complexified vision* of complexity and education (see Fenwick, 2009, p. 112). A vision which encompasses new kinds of complexity, like generative, emergent complexity. A vision which takes education as *both* process-oriented *and* possibility-oriented. A vision which shows the very much *hidden, unknown* complexities involved in education, with complex unexplored possibilities, waiting to be explored in the Age of Complexity.

A Complexified Vision of Education

... all entities in the natural world, including us, are *thoroughly relational beings of great complexity, who are both composed of and nested within contextual networks of dynamic and reciprocal relationships* (Spretnak, 2011, p. 4; italics in original)

It will be possible now to formulate a new, so-called “*complexified vision of education*” (Fenwick, 2009, p. 112). A complexified vision which is enabling and inspiring for *imagineering* education *anew* in the Age of Complexity. One, which is about dynamic web-like units of learners, with their web-like relations, operating as “*cooperative educational relations*” (Sassone, 2002, p. 122). These relations are enabling for *co-creating* each other, with the complex potential of bootstrapping each other upward into each other’s Space of Generativity. This possibility of bootstrapping is showing the potential of an *unlimited enlargement* of cognitive functioning within new spaces of possibility. This enlargement describes a complexified vision that takes Vygotsky’s view about learning and development as a fundamental and foundational *complex* view: with learning and development as a complex, *generative* process of dynamic interweaving between the *inter*-dynamic level and the *intra*-dynamic level of learners involved in interaction. A generative process of dynamic interweaving, with dynamic *inter*- and *intra*-generative emergence, with its potential nonlinear effects *generated* over time (Jörg, 2016). This dynamic interweaving is at base of the fluid, generative processes and generative scaffolding structures that *generate* the complex dynamic, evolving capability of generativity. These processes are fully interconnected in a complex way (cf. Jörg, 2009, 2011, 2016). This complex process of dynamic interweaving describes the coming into being of learners as *complex* human beings, enabled through generative processes of becoming, being operative within web-like relations. These relations may operate as scaffolding *generative* relations, thereby operating as “*transitional scaffolds* in Vygotsky’s sense” (Griesemer *et al.*, 2014, p. 385; emphasis added). The aim of all this interweaving is the achievement of individual and collective generativity, which may operate as the *generative motor* of human development of the learner(s) involved, with their

complex, dynamic, ever-evolving capabilities. The generative processes involved may operate as processes of bootstrapping: *both* of self-bootstrapping *and* of mutual bootstrapping, with both processes thriving on the full generative power of interaction (cf. Bruner, 1996; and Jörg, 2016, 2017). These complex processes are opening new Spaces of Generativity, showing trajectories of *unlimited enlargement* of cognitive functioning, enabling for the unexpectedly complex development of the learner, like Vygotsky's 'transitory child' (Vygotsky, 1987, p. 91; emphasis added). The child as a learner may actually *become* transitory by achieving generativity, individualization and literacy as complex, *generative* states of human being (Sassone, 1996, 2002). These generative states of *being* are enabling for the complex human power of "knowing how to go on" (Lord, 1994). All of this may offer a new way of thinking about the aim of education for the persons involved: that is, in terms of "knowing is *doing* is *being*" (Davis, 2004, p. 154; emphasis added). We may then finally become able to answer the fundamental question of human *being* as a complex question about the very complexity of *human* being of a person: "[W]hat is this person able to *do* and to *be*?" (Nussbaum, 2012, p. 20). This fundamental complex question links closely with the purpose of "enabling people to live full and creative lives, developing their potential" (*ibid.*, p. 185). All of this concerns the very *quality of life* itself (*ibid.* p. 186; emphasis added).

Conclusions

All of the new thinking in complexity about the very *possibility* of education may result from a complexified vision, being part of and resulting from a new theoretical paradigm: the paradigm of *complexifying*, as a fundamental and foundational *bottom-up* paradigm (see Johnson, 2001, p. 67). This new paradigm is enabling for the new thinking in complexity about complexity as *generative*, emergent complexity. This is opening new spaces of possibility like the Zone of Generativity (Ball, 2009, 2012) and the multi-dimensional Space of Generativity (Jörg, 2016). The new theory may replace the *defective, incomplete* theories that still dominate policy-making (Nussbaum, 2012, p. 186), also in education.

We may now come to the conclusion that to conceive of the very *possibility* of education in the Age of Complexity, we urgently need a *complexified* vision of education, so to become able to account for the development of "the individual as a whole" (Vygotsky, 1997, p. 348): that is, as a complex whole with complex fluid, dynamic, ever-evolving capabilities (Nussbaum, 2012, p. 21). These complex capabilities may be taken to be linked with the *quality of life* (see Nussbaum, 2012, p. 186). From this new complexly generative perspective, based on the new paradigm of complexifying, we may better understand that *complexifying* the vision of education may imply the *humanizing* of education. The new paradigm of complexifying then may finally replace the 'blinding paradigm'; the paradigm which has made scholars blind to the problem of complexity (Morin, 2001, 2008). The paradigm that also made us blind for the 'quality of life' (Nussbaum, 2012, p. 186). Education, then, may be viewed as a complex *opportunity* for coming into presence as a *complexly human* being: that is, as "a *continuation* of *procreation*, and often a kind of *beautification* of it" (Sassone, 2002, p. 48; emphasis added; cf. Hansen, 2015, on education as a beautiful *risk*). In essence, then, education may be taken as the complex *realization* of the human being as a *living* human being (see Maturana & Varela, 1980; and Nussbaum, 2012). This may be realized by opening and enlarging the complex spaces of the possible as complex spaces of opportunities, enabling for generativity and individualization as complex dynamic *states of being*; states which are ever-evolving as very complex possibilities and potentialities through generative

processes of dynamic interweaving within the scaffolding generative relationships of self-generative unities of learners.

To fully understand the new complexity-inspired design approach of “Imagineering education” for complex, *living* human beings and their coming into presence as *whole human beings*, you first need to understand that “[A]ny theory of *being* must engage with the fact that to be a *living* presence is more a matter of dynamic, creative responses in webs of relationships than is a matter of categories and substances” (Spretnak, 2011, p. 55; cf. Nowotny, 2013). Based on such a theory of complex being about complex, fluid, human being, we may become able to think of a new generative, transformative pedagogy, encompassing the notion of the *transformative* “we” (Sassone, 2002, p. 123). That represents a new dynamic unity: the very complex, dynamic, self-generative unity. The actors in this unity may operate as a kind of ‘generative bricoleurs’ (Sassone, 1996, p. 520). A complex unity which encompasses *transformative* processes of dynamic interweaving within web-like networks and their “web dynamics” being operative within webs of “*emergent* dynamic relationships” (Spretnak, 2011, p. 17).

With the complexified vision of education, sketched above, we may come to the conclusion that it is possible to *re-think* and even to *re-invent* education in the Age of Complexity. We hope to have convinced the reader that it demands for a new way of thinking in complexity about the true nature of complexity, as based on a new paradigm of complexifying. The reader should, however, may also have understood that the complexity perspective, sketched above, is still *very much under construction* (cf. Arthur, 2015, p. 90; emphasis added), like the theory of education itself.

The new paradigm of complexifying may also be taken as opening for a *new* kind of theorizing pedagogy: to be taken as a *generative* pedagogy. One which is also foundational for a *transformational* pedagogy. This pedagogy can be based on a deep understanding of the very *generative* nature of complexity, showing its potential for enabling generative emergence and potential nonlinear emergent effects. The new paradigm of complexifying may finally make an end to the inherent *trivializing* of the learner in education (von Foerster, 1993). With Edgar Morin (2002), we support the view that complexifying implies a way of humanizing. This may open the *humanizing of the learner* as a complex human being, with the power to develop complex human capabilities through interaction with others (Nussbaum, 2012; Vygotsky, 1978). This humanizing may show the very *possibility* of the developing child as a complex ‘transitory child’ (Vygotsky, 1987, p. 91). This complex concept can be based on the understanding of the complexities involved in what Vygotsky (1978) called “*transitional psychological systems*” (p. 46; italics in original). The *unexplored* possibilities of these systems may be linked with the self-generative unity, as a complex, fluid, generative dyadic unit, described above. We may think of a complexified vision of human being as a *transitory* way of coming into being, enabled through generative processes of becoming self-generative within relations with others (cf. Vygotsky, 1978, p. 57). This complexity of human being may be linked with the complex capability of being *self-generative, self-realizing* through generative processes of becoming (cf. Maturana & Varela, 1980; Nussbaum, 2012). That is, with the very *quality of life* itself (Nussbaum, 2012).

Reinventing education may now be conceived in terms of *organizing* generative complexity as emergent complexity, being operative in self-generative unities as *transitional* systems. This complexified view of education is opening new generative spaces of possibility for education. It is also opening for complexifying the learner as a complex, *generative, transitory human being*. These openings may show the power of new thinking in complexity

for opening the very possibility of reinventing education. This may be opening as well the possibility of reinventing schools (Darling-Hammond *et al.*, 2016).

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