

**Constructivist theories**

Paul van Geert

Department of Developmental Psychology

University of Groningen

Grote Kruisstraat 2/1

9712 TS Groningen

The Netherlands

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## **Introduction [section]**

Constructivism refers to the rather loose and fuzzy collection of approaches to development, human action and particularly education, including the theories of Piaget and Vygotsky (Piaget, 1954; Vygotsky, 1962). In this entry, we shall first focus on the meaning of ‘construction’ and ‘structure’, and explain how these concepts relate to developmental change. Then, the concept of structure will be discussed in the perspective of the concepts of function and agency, and we shall explain how the relationship between these concepts can lead to a theory of development. Finally, we discuss a number of questions that arise from this particular view on the nature of development.

## **Concepts of construction and of structure [section]**

### *Etymological roots of construction [sub-section]*

The word *construction* is derived from the Latin ‘com’, meaning together, and ‘struere’, meaning to pile up. The Latin word *construere* means piling up together, accumulating, building, making or erecting. Constructivist theories thus attempt to explain development as the result of a process of bringing together, a building process. It is assumed that things in general do not automatically assemble into meaningful units, and thus the processes of building, bringing together, piling up must be activities that are performed by an agent. Constructivist theories require agency. Theories of agency tell us that agents are characterized by intentions or goals, by means and tools to accomplish these intentions or goals, and by the possibility to evaluate to which extent the agent's current activities have contributed to achieving a particular intention or goal (Van Geert & Steenbeek, 2005).

The notion of construction is closely related to the notion of *structure* (‘struere’ being a root element of ‘construction’ as well as of ‘structure’). Hence, whatever develops most have the properties of a structure, namely, an assembly or arrangement of elements that has some intrinsic stability. In order to guarantee the stability of such structures, it might be necessary to perform a certain level of continued maintenance, but the implication is that the process of building itself is

transient, and that it comes to a halt when the structure is finished. The question then is when, where and at which point is a particular developmental structure ‘finished’ and how does the builder or constructor know that it is so.

Note that in this entry, ‘structure’ refers to the relationships between the components of a particular body of knowledge, a skill, activity pattern or anything else that characterizes a developing competence of the person. Take for instance a child's knowledge of arithmetical operations, where structural features might refer to aspects such as the reciprocal relationship between addition and subtraction, in the form of the child's understanding that addition is the inverse of subtraction and vice versa. Hence, cognitive structure is not the same as neural structure, although it is clear that every cognitive structure must be implemented in the form of some sort of neural structure (e.g., see Park & Friston 2013). Theories of neural constructivism (Westermann *et al.*, 2007) attempted to explain how brains can develop the neural networks necessary for performing complex cognitive skills.

Being a theory of knowledge construction, constructivism refers in the first place to the building of mental, or neural, structures corresponding with human knowledge and skills, varying from knowledge about the concrete properties of one's immediate environment to knowledge about fundamental abstract properties of reality, such as the concept of number or of causality. The skills that are built vary between sensorimotor skills such as the ability to walk or to ride a bike to cognitive skills pertaining to understanding and analyzing complex structures of relationships between aspects of physical, social and psychological reality (Fischer & Bidell, 2006). In principle, constructivism may also refer to the building of material objects and symbol systems that serve as tools for knowledge. This kind of building in principle amounts to joint activity on the time scale of intergenerational processes, involving cultural communities of collaborating agents. In short, constructivist theories of development focus on processes involving active agents performing processes of construction that lead to intrinsically stable structures or arrangements in the form of patterns of knowledge or skills, including physical objects and symbol structures that serve as their external tools.

*Notion of primordial state in the bridging of the sensorimotor gap [subsection]*

Knowledge, being part of human agency, must be intimately related to other aspects of agency: it must serve the successful fulfillment of the organism's goals, needs, and opportunities. In addition to being functional, human knowledge has a number of features that are quite unique in the biological realm. It involves an understanding of abstract concepts, relationships between concrete as well as abstract concepts, relationships among relationships, systems of relationships, and logic and logical systems (Fischer & Bidell, 2006). Human knowledge also involves the ability to reflect on these properties and to define them in scientific, philosophical and mathematical terms. For simplicity, we shall call these properties 'higher cognitive properties' or 'higher order properties of cognition'<sup>1</sup>. Classical constructivist theorists, such as Piaget or Vygotsky, were intrigued by the nature of these higher-order properties, and tried to understand them by studying the way such properties came about, evolved or developed, that is to say the way such properties originated from a state of cognition where such properties were typically lacking. Let us for terminological convenience call this state the primordial state of cognition, which is basically any state that we take as a starting point for a description and explanation of a cognitive developmental or evolutionary process (Van Geert, 1986).

For constructivism, the question of how these higher-order properties come about, or emerge, out of a primordial state is a question about principles and basic mechanisms, and about the features of *process causality*. This process refers to the principles that describe the dynamics of a particular causal sequence of events that forms a process, such as a developmental process or biological evolution.

From the very beginning of development, the activities of organisms, including the human species, can be understood as activities unfolding in a **sensorimotor realm**, that is to say activities that coordinate sense perception and motor action. The major problem for the explanation of human cognition, however, is the bridging of the sensorimotor gap, the gap between on the one hand knowledge that can be entirely described in terms of sensorimotor

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<sup>1</sup> There is, by the way, no relationship between the 'order' of cognitive properties and the difficulty or complexity of explaining them; that is to say, an explanation of 'lower order' cognitive properties such as the ability of an organism to move around in space is at least as complex as its ability to solve a differential equation or entertain a discussion.

organization, and on the other hand knowledge that requires principles of organization that escape the confinements of the sensorimotor realm.

*Concept of structure in constructivist theories [sub-section]*

A constructivist explanation is not possible without a good understanding of the nature of the structures that are being generated. For constructivists, and we can take Piaget as the prime example of a constructivist scholar, the question about the structure of human knowledge has always far extended the limits of psychological research. In order to understand how mathematical or logical thought or language develops in individual people (or, eventually how it develops across generations during the process of the historical development of a society), we need to know the characteristic features of mathematics, logic or language. The main source of knowledge about such features are the scientific disciplines of mathematics logic and linguistics themselves, or the scientific disciplines studying their history or evolution. This is the reason why foundational scholars such as Piaget or Vygotsky had such a keen interest in the sciences of mathematics, logic or social, cultural and technological history as they were developed during the historical era in which their works took form. Due to his early death as a consequence of tuberculosis, Vygotsky's theory on human development, can only be reconstructed from a fraction of the number of pages that Piaget wrote during his long active life. It amounts to a treatise on the nature of human history and on the historical nature of human knowledge and technology (e.g., see Valsiner & Van der Veer, 1991). Piaget's focus on structure was certainly inspired by the structuralism of his day, but Piaget has always taken a personal and idiosyncratic stance toward structuralism (see his treatise on structuralism in Piaget, 1971). There are two points at which Piaget structuralism deviated from mainstream structuralism, namely, his emphasis on the dynamical nature of structure (as something that happens in time and is constructed over developmental time) and his stress on the importance of the intentional agent and intentional action as the source of the formation of the structure.

*Overarching notion of system and the meaning of structure [sub-section]*

In order to understand what structure means, we can start with the concept of *system*, which means any set of related, interacting or interdependent components that, as a consequence of those relationships, form a unified whole. Hence, human knowledge and skills form a system in

the sense that they consist of components, such as items of knowledge, or specific skills, that are related, interacting or dependent of one another. Such relationships or dependencies may be simple and highly specific, like in associations between concepts such as ‘cat’ and ‘mouse’, but they might also be quite complicated, such as a person’s understanding that a particular political ideology is to a great extent but not completely in opposition to another particular political ideology, or they may be quite general and overarching, such as a person’s understanding of physical phenomena in terms of systems of systems (e.g., neo-Piagetian analyses of the structural properties of thought; see Fischer & Bidell, 2006), or a child’s implicit understanding that every operation on an object as an (imaginary) inverse that undoes the effect of this operation.

Structure can be defined as the whole of relationships that characterizes a system at all possible levels, including a specification of the kind of components that can entertain such relationships. Structure is typically recursive, in the sense that what can be conceived of as a structure on one level of organization, (e.g., relationships between concepts conceived as components of a particular network of relationships) can be treated as a component on another level of organization (e.g., relationships between structures of relationships between components). This property of recurrence has been strongly emphasized by neo-Piagetian theories such as Kurt Fischer’s framework of levels and tiers of cognitive organization (Fischer & Bidell, 2006). Recurrence also features in Piagetian mechanisms such as reflection (taking the content of particular activities as a subject for another type of activity namely reflective abstraction; Piaget, 2001), or in Vygotsky’s analysis of the emergence of scientific concepts (Vygotsky 1962).

A typical formal representation of structure is in the form of graphs: mathematical structures that describe networks consisting of nodes, also called vertices, and lines (edges) that connect them, and that represent the relationships between these nodes. The formal study of such graphs and networks is the subject of **graph theory** and **network theory**. Current network theory focuses on the dynamical nature of networks, for example, how such networks change in terms of composition and relationships over the course of time as a consequence of their own functioning (e.g., Fischer & Van Geert, 2014). In fact, this dynamical interpretation fits in very well with Piaget’s notion of structure as a system of transformations (Piaget, 1971).

Of particular interest to constructivists is the structure of (cognitive) operations, namely, all transformations that apply to objects (e.g., turning an object around), properties, or operations themselves (e.g., applying the inverse operation of subtraction to undo the effect of an addition). Mathematical analyses of the general properties of operations, for instance, by category theory, or by the mathematical theory of groups and symmetries have provided a very abstract treatment of these general properties, and earlier work on the mathematics of structure (and the structure of mathematics, for that matter), has always been a very important source of inspiration for Piaget.

*Structure and its transformation [sub-section]*

Structure implies that there exist specific constraints on its components and relationships. These specific constraints are of fundamental importance as soon as the transformation (i.e., change) of the structure is at stake, which is the case if structure, such as cognitive structure, is something that develops. There can be *structure-preserving transformations*, which is when components and relationships are changed or are replaced by other components and relationships without changing the (higher order) structure. For instance, a typical Piagetian analysis of structure-preserving transformations would involve a baby using his grasping scheme (a sensorimotor structure) to grasp a toy from a variety of spatial starting positions (each starting position serves as a replaceable component in the grasping scheme, i.e., the structure of grasping). This sort of transformation is what Piaget called assimilation. But constructivist developmental theories also address transformations that change a structure, for instance, developmental transformations that lead to more complex or higher cognitive structures. If structure implies a pattern of constraints on transformations, then also these structure-altering transformations are subject to specific constraints. Thus, a particular structure present at this moment allows only for a very limited and very specific set of possible structure-altering transformations in the next moment ('moment' being any appropriate time span). In that sense, structure-altering transformations cannot be based on mere random variation, but must be based on a form of variation that is severely restricted by the current possibilities of the present structure itself. In Piaget's theory, structure-altering transformations (e.g., as a consequence of experiencing problems with the application of a particular structure such as the grasping scheme) are referred to as accommodation.

## **Constructivism and the theory of developmental complex dynamical systems [section]**

### *A dynamical interpretation of structure and the problem of novelty [sub-section]*

In his book on structuralism, Piaget (1971) emphasized the distinction between structure as a formal or formalized representation of a pattern of relationships, and structure as the property of psychological and cognitive operations and activities. The former notion of structure refers to static patterns, which are independent of time. On the other hand, structure as a property of cognitive operations must be something that exists in or unfolds over time, as cognitive operations and activities are inherently spatiotemporal processes. Piaget describes structure as a system of transformations, and these transformations involve laws (Piaget, 1971, p. 5). For instance, if A and B are elements of a system, and  $r$  is a symmetric relationship between A and B, then  $r$  is a way of getting from A to B and vice versa, which is basically the same as saying that  $r$  is a way of transforming A into B and vice versa. The laws that govern these relationships or transformations are in fact similar to relations between relations (i.e., transformations of transformations), and are thus part of the structural description of a particular system. Piaget relates these laws (let us for simplicity call them higher-order structural properties) to what he considers a central feature of structures, namely, their wholeness, structural completeness or closure. However, there exists an inherent conflict between the property of structural completeness on the one hand and the possibility or necessity of structural change. How can a closed structure escape its own inherent limitations<sup>2</sup>?

The constructivist answer to this conflict is that structure-driven change comes about as a result of the functioning of the structure in the context of human agency. For instance, a baby's knowledge of objects consists of various interrelated components (various objects, various movements of objects, etc.), and these relationships have a particular structure. The baby's activities with objects (e.g., trying to retrieve an object that is currently out of sight) are guided by this knowledge, and it is through this activity that the baby's knowledge, including the knowledge structure, is changing (Van Geert, 1998 provides a mathematical model of this type of change process).

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<sup>2</sup> It is this seeming impossibility that led Fodor (1975) to formulate the impossibility of novelty construction in development, and the hypothesis that all cognitive structure that can ever be achieved during development must be innate.

As part of his intrinsically dynamical approach to structure, Piaget invokes the notions of self-regulation and equilibrium, entailing self-maintenance and closure (Piaget, 1971, pp. 13 & 14). Self-maintenance and closure imply ‘final’ structures, i.e., structures in which all transformations are automatically structure-preserving. In other words, all perturbations of the structure, such as in the form of experiences that contradict the structure, can be counteracted by means of structure-preserving transformations. Imagine a magician conjuring up a rabbit from his high hat, giving us the impression that objects can emerge out of nothing, which clearly contradicts our basic beliefs about objects. However, given what we know about magicians, we assume that the rabbit is already there, although we could not see it (which is a belief that compensates for what we see, and thus preserves our model of the world in which things cannot emerge out of the blue). Piaget viewed the process of the construction of knowledge as self-organizing: the principle of autoregulation not only applies to the finished cognitive structures (the structure-preserving or stable levels), but by necessity also applies to the entire lifeline of those cognitive structures and thus also entails their genesis.

*The theory of developmental complex dynamical systems[sub-section]*

This explicitly dynamical interpretation of structure brings Piagetian thinking in close contact with modern theories of dynamics, namely, the theory of complex dynamical systems (Van Geert, 1998), in which the notions of system (relationships among components), dynamical relationships (transformations), self-organization, self-maintaining attractor states, active resistance to perturbation and return to stability of a particular attractor state after perturbation, and finally the existence of attractor landscapes (the existence of various self-maintaining states) are central concepts to which those of Piagetian theory can be easily subsumed. The modern theory of complex dynamical systems adds an important foundation to the original Piagetian scheme of explanation. Because it focused on structural closure, Piagetian theory had in fact serious difficulties explaining developmental transformation in the sense of structural ‘openness’, (i.e., the possibility of creating novelty and the formation of truly novel structures in the sense of developmental emergence, which refers to structure altering transformations).

In order to explain the creation of novelty, the theory of complex dynamical systems refers to the fundamental property of *emergence*. Emergence means that particular properties of

structural components, and the patterns of relationships they can entertain, may, under certain conditions, spontaneously result in the arising of novel properties (i.e., properties that do not apply to the relationships and components that gave rise to them). An example is the emergence of V-form flight patterns in migrating geese. It is quite certain that individual geese are not equipped with innate or learned instructions that pre-specify the form of the flight formation (this is different from pilots of fighter plane squadrons who do have pre-specified flight patterns when they fly together). The flight activity of individual geese is governed by very simple principles of energy reduction and sensory flight control, and the V-patterns emerge spontaneously from the way geese interact with one another, trying to find the best possible energy reduction and sensory information during flight. In addition to there not being a pre-specified flight pattern in the geese, there is also no flight commander goose telling his subordinates to follow him or her in the form of a V-pattern. In summary, emergent patterns result spontaneously from simple activity principles in the interacting individuals.

The emergence of cognitive structure is the direct consequence of activity patterns governed by deep properties of organization of the brain-body-world system, more precisely its organization in the form of nested and interacting components, with the interactions taking place on various connected time scales (Fischer & Van Geert, 2014; Van Geert, 1998). Thus, although the developing person is active in constructing the *conditions* of development in the form of intentional activity, it undergoes the effects of the resulting processes of emergence. The developing person may then act intentionally on the results of these emergent processes, thus creating a continuous and recurrent loop of emergence and intentional action..

Emergence is the process by means of which a system bypasses the property of closeness or wholeness (e.g., the system of sensorimotor structure). Closeness means that those structural properties, such as sequential temporal relationships between the consecutive steps of a particular activity, the ability to bypass physical obstacles in order to reach a particular goal, the ability to take the existence of an object into account even if it does not directly visible, and so forth, suffice to organize every possible sensorimotor activity. That is to say, the agent does not need any other, additional structural properties to perform a sensorimotor act, and in this sense, the sensorimotor structure of a competently acting baby forms a 'closed' or 'whole' structure. However, this closed whole of structural properties is not sufficient for defining or guiding

activities of an entirely different nature, for instance, the operational activities characteristic of later stages of development. The structural principles governing these activities, such as the principle of logical reversibility, are clearly outside the boundaries of the system of sensorimotor structural principles (i.e., they are outside the sensorimotor closure). If the principle of emergence applies, however, there exist forms of organization of sensorimotor structures that lead to emergent properties such as operational structures. The actual question for constructivism is: what are these forms of organization that have these particular emergent properties?

The question of the emergence, of how cognitive novelty originates, is a question for constructivism as well as for dynamical systems theory of development (e.g., Thelen & Smith, 1994; Van Geert, 1994). A crucial distinction between constructivist theories and dynamical systems approaches has to do with whether or not there is something like a ‘controller’ of the system. Constructivism is based on the notion of activity, involving an agent as the controller of the activity (see further). By invoking the principle of self-organization, dynamical systems theory appears to do away with such an agency. However, we must make a clear distinction between the agent as controller of his or her activity, and the agent as controller of the construction of his or her cognitive systems. In this section, we have stated that the construction of cognitive systems can very well be interpreted as the self-organizing result of the way the agent controls his or her activities.

*Transformation of structure and the notion of construction [sub-section]*

When we reflect on the notion of construction, it is likely that we spontaneously imagine an *allomorphic* form of construction: a process governed by some external form or structure, such as a building plan, may govern the construction of the house, or a curriculum may govern the construction of a particular kind of knowledge (e.g., a math curriculum). These external, guiding structures may be physical or symbolic, external or internal (e.g., an internal representation of a particular thing that one wants to construct). In principle, allomorphic construction implies that the resulting structure starts to function as soon as it is finished (i.e., as soon as the resemblance or isomorphy with the external structure is achieved). For instance, if one constructs a house, it is inhabited meaning that it starts to function in accordance with the intention of its construction, only after its construction is finished (i.e., as soon as structural closure is achieved). All the preceding states of the house are, in a sense, incomplete, (literally) non-closed structures.

It is highly unlikely that development is governed by a form of allomorphic construction. For example, there is no way in which the sensorimotor structures can be guided by a building plan that represents the intended level of operational systems, because that would imply that such structures can implement a representation of operational systems, which means that they are no longer sensorimotor structures (see also the section on Constructivism and the theory of developmental complex dynamical systems). In addition, the builder of the knowledge (e.g., a particular child) cannot afford to wait to use the cognitive structure until it is fully finished, as is the case with the house under construction. Cognitive tools must be put to use as and while they are being constructed. This is a major feature of ontogenetic development, and the fact that cognitive tools must be put to use while they are being constructed determines to a considerable extent *how* development takes place.

One way to overcome these problems is to assume that all construction is guided by someone who is mature enough to represent the building plan of the finished structure, such as, an adult or a teacher who is capable of thinking in terms of operational systems. This is basically the solution not of construction but of *instruction* (i.e., of transmitting structure from outside). However, this solution puts us in an infinite regression, since it requires another adult who instructed this adult, and yet another one who instructed the former one and so forth, ad infinitum. Another problem with instruction is that it requires a process of meticulous and continuous guidance of the instruction process, and it may be questioned whether such guidance is at all practically possible. Yet another answer to the constructivist paradox of allomorphic construction is the possibility that the final structure, that of operational systems, is already present at the beginning of the life of the constructing person, an answer more commonly known as nativism. However, nativism suffers from the same problem of infinite regression as does the instruction solution.

One way to solve the infinite regression is by replacing it by a process of finite regress, suggested by Dennett (1991), for instance, by showing that the function of an internal controller in the brain can be explained on the basis of simple mechanistic neural networks. However, it is likely that every level of organization (e.g., that of neurons, that of networks of neurons and so forth, is characterized by its own emergent properties that are not reducible to properties at the lower level (e.g., networks of neurons having properties that cannot be reduced to the properties of individual neurons). If that is so, finite regress itself does not answer the question. There is

also the solution of neural Darwinism proposed by Gerard Edelman's theory of neuronal group selection, which holds that development starts off with non-instructive sensorimotor systems that can adapt to their environment via the mechanism of selection. However, the problem of a selection-based Darwinist explanation is that it must also have a theory on where the variation on which selection operates comes from, and what kind of variation this is, given the current state of a developing system. Providing such a theory is what epigenetic, developmentally-oriented theories of evolution are attempting to do.

In short, for constructivism, allomorphic construction cannot be the solution to explaining the developmental process. To do that, we need another form of construction, *automorphic construction*, a construction process based on the principle of emergence that is governed by what has already been constructed. So, at any time, the temporary result of past construction activities determines the next step in the construction process. In other words, construction is typically an iterative process (the product of the preceding step determines the next step), and in that sense automorphic construction complies with the general definition of a dynamical system (Van Geert & Steenbeek, 2005).

Automorphic construction can be described as follows:

1. It is a sequence of activities of transforming (including adding and removing) components and relationships to/from an existing structure  $S_t$  (a structure at some moment in time,  $t$ ). These activities can be carried out at the individual level, on the level of small-scale social interaction (e.g., dyadic child-child, or student-teacher interaction in real time), or on the level of large-scale collaborative structures (e.g., groups of people collaborating to achieve a common goal)
2. The transformation of the existing structure,  $S_t$ , that results from the sequence of activities occurs in accordance with the structural affordances/constraints governing the existing structure,  $S_t$ , which is similar to saying that the activities of construction are controlled by the function of the structure at time  $t$  (i.e., by what the structure *does* at time  $t$ ).
3. These processes of transformation result in structural transformations that are (either) structure-preserving and/or structure-altering, which can occur at various structural levels, depending on the structural affordances/constraints at time  $t$ . More precisely:

- a. The transformations can preserve the general structural principles and alter specific ones, such as when a particular cognitive structure is extended with a new application
- b. The transformations can alter general structural principles, and introduce a potential variety of new, specific applications and principles, which is typical of states of emergence of new properties or major developmental discontinuities (e.g. Piagetian stages).
- c. If construction processes result in a state of the system in which only general-structure-preserving transformations remain the system has come to a state of self-maintained stability (e.g., Piaget's notion of equilibration); whether or not self-maintaining, stable structures will result from the construction process (stable attractors in the jargon of dynamical systems theory) depends on the nature of the structures in the construction process

This description of the properties of automorphic construction implies a variety of theoretical and empirical questions with regard to development. For instance, how much of the processes of development or learning can be described as allomorphic, and how much should be described as automorphic construction? What kind of activity level is typical of developmental or learning processes: activity on the individual level, or on the level of dyadic interaction between persons at different levels of development? In addition, developmental construction processes may differ as to whether they finally lead to self-maintaining structure (at the general level of organization) as Piaget's and neo-Piagetian theories clearly imply, or whether they lead to structures that will ever expand into new emergent properties, as a cultural-historical theory of knowledge construction implies. Construction processes may differ as to whether they lead to gradual change or whether they go through a process of discontinuous reorganizations (the latter is typical of the Piagetian and neo-Piagetian theories, as well as dynamical systems theories).

Insert Figure 1 about here

Insert Figure 2 about here

*Constructivism and the focus on high level properties of cognitive structures [sub-section]*

Given that the structure of human knowledge and skills can be defined on so many levels of detail, constructivists have been trying to focus on the major structural properties of human knowledge and skills (i.e., on that what is really fundamental in all the possible types of actual

relationships between actual components of knowledge and skill). An example of such high order structural property is the *reversibility* of operations, a theme that was of fundamental importance for Piaget, because according to him, the developmental construction of the property of reversibility marked a fundamental developmental transition from real or imagined actions to the level of *operations* (i.e., actions with transformations characterized by reversibility). Reversibility means that every operation has an inverse operation that will undo the effect of that operation, the effect of which is ‘no change’. According to Piaget, reversibility typically develops around the age of 5 to 6 years, and marks a transition from a pre-operational to an operational mode of thought. Another example is the neo-Piagetian analysis of the general structure of cognitive representations, for instance in the form of nested relationships (Fischer & Bidell, 2006; Mascolo, van Geert, Steenbeek, & Fischer, 2015; see Fig. 3).

Insert Figure 3 about here

## **Structure, function and agency [section]**

### *Function, functioning and intention [sub-section]*

A system is not only characterized by structure, a pattern of relationships among its components, but a system also shows a particular kind of behavior, according to which it can do certain things, or can be used to do certain things. For example, the system consisting of material components constituting a house fulfils a wide variety of lodging functions, and relationships that constitutes the knowledge about our cat can be used to predict the time she needs to get milk or food.. This is what we can call the function or the functioning of the system. The word function is derived from the Latin *functionem*, where it means a performance or an execution (in the sense of something being done). If we deal with human systems, such as a person’s or a society’s body of knowledge, we are automatically confronted with the very basic fact that humans are agents, in the sense that they are pursuing certain goals, have intentions, have tools to reach such goals or to realize their intentions, that they are evaluating the world in terms of their goals and intentions and of their degree of success in reaching their goals (Steenbeek & Van Geert, 2007). We can call this feature of human agency *intentionality*<sup>3</sup>, in the sense of ‘doing something with an intention to

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<sup>3</sup> This notion of intentionality is different from the general philosophical notion of intentionality which basically means ‘aboutness’, and which is conceived of as the primary property of the mental domain (i.e., in the sense that mental states are always ‘about something’). The current philosophical concept of intentionality, which was already known in medieval scholastic philosophy, owes its meaning to the 19th century

realize something' or 'on purpose'. Intentionality does not require that goals be consciously or deliberately represented, and also covers processes that occur outside an organism's cognitive or conscious control, such as the intention to maintain physiological homeostasis of the body. Hence, any structural feature of human knowledge must be seen in terms of the perspective of the property of *agency*, and agency defined by intentionality. M

The notion of intentionality (in the sense of intention-ality) is notoriously difficult to describe in exact terms, and various philosophers, and in particular Daniel Dennett (1982) have argued that in order to explain (human) behavior, various perspectives can and should be taken into account. One such perspective, Dennett calls it a stance, is the intentional stance, which means that human beings are described from the perspective of having a mind, and having a mind is interpreted as having beliefs, desires, motives and so forth. That is to say, it is a perspective on human beings as rational agents, actively pursuing their goals and desires. Another such perspective is the physical stance, which implies a look at an organism as a physical object governed by physical laws, such as the laws of physical, complex dynamical systems. The question is not which one of these stances is true. The question of whether a human being is a rational agent equipped with intentions, goals and motives, *or* whether it is just a physical machine governed by mere physical laws, should be considered meaningless. Rather, the fact that several perspectives on the same object are possible, appropriate and necessary (e.g., those of intentionality and physical properties and laws), gives us important information on the nature of that object, and is a major source of understanding such objects, and in this particular case human beings.

The intentional stance comes close to the principles of ecological psychology, based on the work of Gibson, which views all behavior in terms of organism-environment couplings. Organisms directly perceive their environment in terms of affordances, that is to say, specific opportunities for action, defined by their abilities and associated goals for action. For example, an adult will perceive this particular page as an opportunity for reading, whereas a baby will perceive it as an opportunity for grasping and crumbling, thus subsuming this particular piece of paper under the general class of soft, light, manually transformable objects. However, if the adult

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philosopher Franz Brentano. In the present context, this notion of intentionality is deliberately simplified to represent aspects of purpose, control etc., and should thus, strictly speaking, be written as intention-ality

is in a cold and damp house with a fireplace, it is likely that this page will be perceived as an opportunity for lighting a fire. That is, these affordances are directly perceived as opportunities of the environment, and opportunities are perceived in terms of on the one hand abilities and and on the other hand the current activity.

Dennett has offered a third perspective or stance on behavior, which is the design stance, (i.e. a perspective on an organism that focuses on the way this organism is designed, irrespective of the exact physical way in which the design is materially realized). The notion of design comes very close to the notion of structure. For instance, a particular architectural structure can take the form of real building, a detailed building plan, or a model. A particular cognitive structure can take the form of neural networks, an abstract mathematical description, or a computer model. The constructivist approach, focusing on cognitive structure, is thus an example of the design stance. However, in line with our earlier remark that our knowledge about a particular ‘object’, such as developing cognition arises from the existence of various, appropriate perspectives on that object, we should now conclude that in order to arrive at the full understanding of cognition and its development, we should try to understand how these three possible perspectives, the intentional perspective, the perspective of physical dynamical systems laws, and the perspective of structure can be related to one another in order to arrive at a comprehensive picture (think of the well-known metaphor of the blind men each touching a specific part of the elephant try to come to an understanding of the elephant by reconciling their perspectives).

#### *Function and agency [sub-section]*

Biological agents are autonomous physical systems, exchanging energy and information with their environment in such a way that the maintenance of their physical and functional integrity is optimized. By physical and functional integrity, we can understand the agent’s physical structure, including all mental structures that rest upon the organism’s physical structure (e.g., neural networks). The exchange of energy with the environment is done by means of specialized internal and external tools, or organs (‘organ’ literally meaning a tool for making or doing something). Much of the energy that an agent exchanges with its environment takes the form of information, that is everything that governs the performance of the agent via choices, perception, decision and so forth. In that sense, many of the organs of the biological agent are tools for processing information, and in addition to the sensory organs, a very important organ in that respect is the brain, which can process energy qua information in a typically recurrent way (information about

information about information etc.). These recursive processes can occur outside the human agent's cognitive control, for example, as feedback loops in the brain, but they can also take the form of conscious recurrence, in the form of reflection, thinking, abstraction and so forth. Piaget (2001), for instance, sees **reflective abstraction** as a fundamental mechanism of structural transformation (i.e., development). For Vygotsky (1962), recursive activities such as consciousness and reflection are of central importance for the process of ontogenesis, as well as for the intergenerational process of cultural-historical knowledge construction.

Broadly speaking, the process of optimizing the maintenance of physical integrity takes the form of specific performances, namely, action that can be described as sequences of goal-directed, interest-laden, intentional, and concern-determined behavior. Biological agents are complex and are finite in time, with a limited lifespan, and will after awhile inevitably lose the battle for maintaining their physical integrity. For that reason, the existence of biological agents implies that they have to reproduce (i.e., produce offspring). In complex organisms, there exist *physical-biological limitations on the initial structure of the offspring*, that is, on the 'primordial state'. How much structure can be transmitted through the process of generating offspring and how much of that structure must be created during the process of growth or development? Given these limitations on the properties of the initial structure of offspring, behavioral functioning must be conceived of as the elaboration of physical, biological, and in the case of humans' mental structure up to a point where the organism reaches a level of complexity where the generation of new offspring is possible. This process of elaboration must take the form of growth and development, leading to self-maintaining structure, loosely defined as the 'mature' form of the biological agent. Thus, all structure, both biological and cognitive, is a form of structure that is constrained by the fact that it must pass through the narrow gates of development. In that sense, construction is not an option, but rather it is a necessity. This necessary process of the emergence of self-maintaining structure takes place on all different levels of organization of the agent qua physical structure, and does so on a wide variety of time scales (e.g., on the time scale of embryogenesis and the emergence of physical structures, and on the time scale of ontogenesis and the emergence of neural networks as tools for specialized, recurrence-based processing of energy in the form of information).

In a sense, a human agent is an autonomous biological system that is generating structure on a variety of levels, and this occurs in such a way that the maintenance of this structure is optimized through the particular way in which a system exchanges energy/information with its environment. Note that this definition is highly reminiscent of the concept of *autopoiesis* as put forward by Francesco Varela (1946-2001) and his mentor Humberto Maturana (i.e., the construction of structure the function of which is to reproduce and maintain that structure). This idea is also reminiscent of the notion of structural closedness, which is also a prominent feature of Piaget's view on structure. Put differently, a human agent is an organism creating internal and external structure with the aim of *maintaining* that structure by using it in exchanging energy and information with its environment. On the ontogenetic or life-span time scale, internal structure focuses primarily on neural networks, the organization of which phenomenologically corresponds with structures of meaning or of understanding that are produced in particular ecological niches, (i.e., in environments with an external structure that realizes an optimal fit with the internal structure of the organism or subject). In human beings, the creation of external structure in one's bio-cultural niche, which as any other form of organismic structure has as its primary function the optimization of the maintenance of that structure itself, typically involves the (cultural, inter-generational) creation of physical and symbolic tools, artifacts, practices, and so forth.

*Relations between internal and external structure [sub-section]*

The relation between internal structure (e.g., in the form of mental skills) and external structure (e.g., in the form of cultural tools, artifacts or symbol systems) is always reciprocal in nature. A book, for instance, exist by virtue of the fact that there are persons who can read it, and the ability of reading exist by virtue of the availability of carriers of written text, such as books.

The reproduction of *external structure* over generations is an entirely different process than the reproduction of the *internal structure* required to use the external structure as tools. The first is a process of manufacturing, economics, material production and so forth; the second requires processes of development and of education, which are in fact rather loosely defined terms. For example, how much of education is a form of simple transmission, how much is a completely autonomous self-organizational process of an individual person made possible by offering a particular context that we call education?. As human beings are social and cultural, the construction of a match between internal and external structure takes place in the form of social interaction (cooperation and competition in a wide variety of forms; Valsiner, 1994), as well as in

the form of intergenerational transmission, production and reproduction in the form of *collective agency* (which can be defined as the form of activity that is performed by a group or collectivity of individual agents, pursuing goals defined on the level of the collectivity, such as an industrial company, or society as a whole)).

In short, any treatment of growth and development must account for the relationships between agency (both individually and collectively), function (in the sense of performance, behavior, activity) and structure (in the sense of the design properties of the tools and ‘organs’ that make this particular functioning possible in such a way that the intentions are optimally met). The necessity of development (development as a biologically and psychologically necessary process) implies the existence of temporal constraints, which are properties that govern the possible order of steps in the process and its rate of change. These constraints thus apply to the development of the relationship between agency (intentionality), function and structure must also be studied in the form of temporal constraints.

*Agency and the dynamical connections between intentionality, structure and function [subsection]*

The entire model of agency is depicted in Figure 4. Agency is always situated in a particular niche of the real world or ‘Umwelt’ (the niche of the world that a particular agent has been given/chosen/constructed and that provides the opportunity of optimal functioning). For human beings, this particular niche is a typically humanly constructed niche, which is the result of social and cultural activities with a transgenerational nature, the products of which can be transmitted to the next generation.

Function is the interchange between the agent and its constructed world. The constructions of that external world comprise physical tools and commodities ranging from pencils to machines to buildings, social structures such as institutions, structures of power and values, and symbolic structures such as linguistic systems or written texts. Given the necessity of development (see above), the causal relationships among the components of agency must be of a dynamical nature that describes how changes in one component are caused by the current state of the component and changes in the other components. For instance, change in function may produce change in structure, change in structure may produce change in intentions, which

produce changes in function etc. These dynamical relationships must take place on at least two different time scales, namely, the short-term time scale of real-time activity (a central feature of agency) and the long-term time scale of development (or of learning, adaptation, evolution and related terms).

Theoretically speaking, the starting point is one of complete interconnection between the three main components of agency in which every component should be dynamically connected to every other one and to itself. A component's causal connection to itself implies that it has a certain intrinsic dynamics, and that it is characterized by self-organization and autoregulation. By emphasizing the latter mechanisms, Piaget anticipated the modern theories of complex dynamical systems.

Insert Figure 4 about here

The constructivist scheme of explanation implies *reciprocal* dynamical connections between intentionality (as in having intentions to do something) and structure (e.g., as in the structure of cognitive tools) since it is likely that intentions will be governed by the affordances and constraints of the structure of the cognitive tools, whereas on the other hand, structure (e.g., of cognitive tools) is likely to change (accommodation) under the influence of intentions, more particularly the success or failure of the structure of the cognitive tools to effectively realize the agent's intentions (Moessinger, 1977). In the cultural-historical view, motives and goals of action are typically related to cultural tools and commodities, and thus emerge in the person as the person learns to use these tools or commodities. Meanwhile, these cultural tools are ways of achieving the goals or realizing the motives that are associated with them, implying bi-directionality between intentionality (the intention of performing certain activities) and the cultural tools, which always imply a connection between internal cognitive and external physical tools or tool systems that are used to realize one's intentions (see theory of activity by Aleksei Leont'ev (1903-1979); Kozulin, 1986).

*Construction as an iterative process [sub-section]*

The bidirectional adaptation between intentionality and the structure of cognitive and physical tools is typically iterative or recursive. This iterative or recursive nature implies that any next step in a constructive process must, by necessity, build upon the preceding steps. Or, put differently,

the preceding steps set very specific constraints and specific degrees of freedom on every next step in the process. The effect of a particular functioning on the adaptation of the structure (e.g., the effect of experiencing a failure, and internal contradiction) is thus determined by the present constraints of the structure. This iterative or recursive nature of the constructive process is in fact similar to stating that the constructive process is governed by an intrinsic dynamics, and its formal mathematical expression is similar to the formal or mathematical expression of a dynamical system. A similar form of iterative or recursive construction is also found in the cultural-historical accounts of the historical development of material and symbolic tools, in the sense that the construction and production of such tools by every generation builds upon the results of the constructive activities of the preceding generations.

Various theories ranging from classical liberal economist theories to Marxist dialectical materialism have tried to explain the nature of the constraints governing the historical and cultural processes. In Vygotsky's case, and in that of his followers such as Leont'ev (1979), the major source of inspiration came from various interpretations of Marxist philosophy. The reason why, for these theorists, the thorough understanding of the structure of the external, humanly constructed world (as interpreted in terms of culturally transmitted and defined abilities, goals and motives of enculturated agents) constitutes a primordial requirement for the understanding of human development is that human development always boils down to a process of internal structural change (of knowledge, skills, symbolic communication) that is required for the agent to make adequate use of these external tool systems and to participate in the development of society. The process of development, in the sense of the personal appropriation of these cultural tools, is like an 'abbreviated' version of the cultural-historical process of tool construction and production. This process of appropriation is made possible by education, where the person's construction of internal tools in the form of abilities and skills occurs under the guidance of an accomplished tutor, educator or teacher.

*Collective and individual agency [sub-section]*

For the cultural-historical theories, the constructed Umwelt of agents is in fact the result of collective agency, that is, agency defined on the level of societies. For that reason, the explanatory scheme of constructive development takes place on two levels of organization, namely, that of the individual agent (e.g., a newborn child, an elementary school child, an adult in

a professional context, etc.) and that of collective agency (see Fig. 5). Individual as well as collective agency are characterized by the aspects of intention (concerns, goals, aims...), structure (of tools and organs) and function (actual performance, teaching, industrial labor...). In fact, function is the meeting ground between individual and collective agency.

Insert Figure 5 about here

It is at the level of the theoretical description of the agent's 'environment' or Umwelt that cultural-historical constructivism crucially differs from biological constructivism (e.g., in the way it was understood by Piaget). Piaget did not primarily conceptualize the world, reality or the environment as a world of collective agency, aimed at guiding the child in a process of construction that without his guidance would never be possible. For him, reality involves the existence of objects in time and space. The nature of this reality is described by the sciences, logic, and mathematics. Hence, in order to understand how children construct an understanding of this reality, it is important to understand the properties of reality, which implies that in order to understand development one has to take the fundamental scientific, logical and mathematical interpretation of the nature of this reality into account.

For Piaget, the description of 'immature' or transient structures for understanding and controlling reality, for instance in young children, will thus always take the form of a confrontation with the contemporary available mature structures for such understanding and control of the world, as they are presented by science, logic, mathematics and technology. That is probably the reason why a scholar such as Piaget used to describe children's logical thinking in terms of the very abstract machinery of mathematical **group theory** and the insights of the **Bourbaki** group of mathematicians, who worked on the foundations of mathematical structure at the time when Piaget was doing his work on development and genetic epistemology. Unfortunately, this particular style of explanation has led to considerable misunderstanding of what Piaget was up to. Basically, what he was saying is that if mathematical group theory can be used to understand the structure of a cauliflower or of a game of cards, then it can also be used to understand the child's cognitive structure. The difference between the cauliflower and the child is that, for children it is *in principle* possible to reflect, at some point in developmental time, on

their cognitive structures, Using principles that mathematical group theory describes in a highly formalized and abstracted fashion is an example in point.

### **Concept of construction as developmental mechanism: Recapitulation and questions [section]**

In this entry, we have seen that the concept of construction is intimately related to that of activity, and more precisely agency. We have also seen that the relationship between these concepts is far from trivial. In principle, activity implies intentionality, defined in this entry as the focus on something to be accomplished. As we have seen earlier, the concept of intentionality is part of a particular perspective on human behavior (the intentional stance). In that sense, intentions are ascribed to a person, and the appropriateness of this ascription depends on whether or not it leads to a consistent interpretation of the person's behavior. We can easily interpret a particular baby's activity as an intentional search for an interesting object that is now concealed from vision (from typical A-not-B error type of search to fully adequate search). However, is it also possible to interpret this particular activity as an intentional construction of the object concept? The latter is indeed a very unlikely interpretation. Nevertheless, in a developmental context, we speak about the child's construction of reality, as Piaget did, or about the child's construction of language (Tomasello, 2003). How can this conflicting use of agent-related terminology be solved?

In this entry, we have explained that the process of construction, for example of cognitive structure or language structure, is basically a process of emergence and self-organization (i.e., a process that is *emergent upon the activities of a person*, but is not in itself a topic of active control<sup>4</sup>). At any time during development, this process of emergence is closely intertwined with the processes of activity, in the sense that as particular processes of activity lead to particular emergent processes of construction, the structures emerging from this construction lead to particular processes of activity. We can call this the **iterative cycle of construction** of cognitive structure and activity. We can postulate a similar iterative cycle of the construction of external

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<sup>4</sup> Active, personal control of learning might have to wait for a much later stage in development and is in all likelihood confined to highly specific goals of achievement, such as the intentional learning of a second language, or the intentional deep practice required to become an expert in a particular professional field.

tools and symbol systems on the one hand, and activity and internal cognitive structure on the other hand.

As the process of developmental construction is an emergent and self-organizing process, and does not proceed under the direct intentional control of an agent, it is possible that these processes unfold in highly idiosyncratic ways, i.e. that they show considerable inter-individual differences. As a result, it is possible that human beings end up with cognitive and linguistic structures that are about as idiosyncratic as the processes that gave way to them. If that would be so, we would have serious problems with communication and with understanding each other (e.g., if our basic understanding of the way the world is, is so different between individuals). One possible answer to this relatively grim scenario is that in spite of the eventual idiosyncrasy of the processes of construction, the end result is one of equifinality, which in itself results from long-term evolutionary and cultural-historical processes that have favored only those end results that are sufficiently common among individuals. That is to say, developmental construction results in self-maintaining states the major properties of which show relatively little variation among individuals, in particular as the fundamentals of the resulting structures of understanding and communication are concerned. One example is the development of a grammar of a particular language, that is obviously so similar among speakers of the language that they recognize each other as native speakers, speaking the same language and having the same linguistic intuitions. Another example is the emergence of logical understanding, as described by Piaget. It is likely that the differences between people in terms of their understanding and interpretation of the world are small enough to allow for **collective agency**, involving cooperation as well as competition, and big enough to fuel a dynamics of cultural historical change that is typical of the human species.

In addition to cognitive structure showing closure in the sense of self-completeness, idiosyncratic pathways of construction might nevertheless lead to cognitive structures that are characterized by high idiosyncrasy. In the constructivist scheme of explanation, cognitive structure can never be and is never meant to be some sort of reflection of the true nature and properties of reality, which means that the construction of cognitive structure is not controlled by the true nature of reality, whatever that may be. Cognitive structure is a complex scheme that

makes reality understandable, controllable and manageable under the constraints and possibilities of the cognitive structure itself. The consequence of this view is what its proponents call *radical constructivism*, which claims that the process of construction is aimed at the emergence of **viable** interpretations of experience, and what serves as a viable interpretation may indeed differ from person to person, thus leading to highly idiosyncratic cognitive structures (Von Glasersfeld, 1990).

As construction is so closely related to the activity of agents, we should ask ourselves what sort of agency must be implied. Is it primarily individual agency, with the child him, or herself, as the sole agent from whose activities the construction of cognitive structure emerges? If this is so, the role of the educator could be interpreted as that of a more or less passive supplier of the right building blocks at the right time. Is it primarily individual agency, but then with the educator as the sole agent? If this is so, the child would be a more or less passive recipient of the educational activity, and the construction of cognitive structure and knowledge would then emerge from the child's undergoing and participating in these educational activities. Or is the process of construction the result of joint agency, where the intentions, goals and activities must be defined on the level of child-educator co-agency (Steenbeek & Van Geert, 2014)? If this is the case, construction of knowledge and cognitive structure is a matter of co-construction (Valsiner, 1994). Finally, it is likely that joint agency, such as that of an educator and a child, does not stand on its own, but can only be understood in terms of collective agency, on the level of societal institutions and the value and power systems governing childcare and education.

## **Conclusions [section]**

Irrespective of whether construction is the result of individual, joint or collective agency, constructivist theories of development need to pay attention to structural aspects of agency other than cognitive structure, namely, that of intentions, goals, drives, interests, values, evaluations etc.), as well as to the aspect of functioning itself. One needs other theories in psychology for a focus on the structure and intrinsic dynamics of intentions (the structure of what 'moves' a person) and on the structure of the intrinsic dynamics of functioning. The former was typically the field of psycho-dynamical theories, beginning with Freud and psychoanalysis, which applied

the notion of structure and the internal dynamics to the person's drives, motives and goals. In cultural-historical theory, however, Leont'ev focused on an analysis of human activity as based on needs and motives (needs oriented toward particular objects), leading to specific goals for action and structures of activity. The focus on the structure of the intrinsic dynamics of functioning, namely, the active interplay between the organism and its Umwelt is typically the field of ecological theories in psychology, such as in Gibson's theory of affordances and the structure of the perceptual-action field, and in the specific form of the developmental dynamical systems theory that is advocated by Thelen, Smith, and others (e.g., Thelen & Smith, 1994). Finally, the combination of principles of constructivism on the one hand and concepts such as emergence, self-organization and attractor dynamics, advocated in this entry, implies that the constructivist program needs to merge with that of complex dynamical systems. The way this merger can be done has so far not been satisfactorily resolved, although neo-Piagetian scholars have attempted to formulate answers, an example being in the form of dynamic skill theory (Fischer & Van Geert, 2014).

**See also:**

**Learning theories; Dynamical systems theories; Qualitative methods; Connectionist modeling; Cognitive development during infancy; Cognitive development beyond infancy; Perceptual-motor calibration and space perception; Language acquisition; Perception and action; Locomotion; Future of cognitive developmental research**

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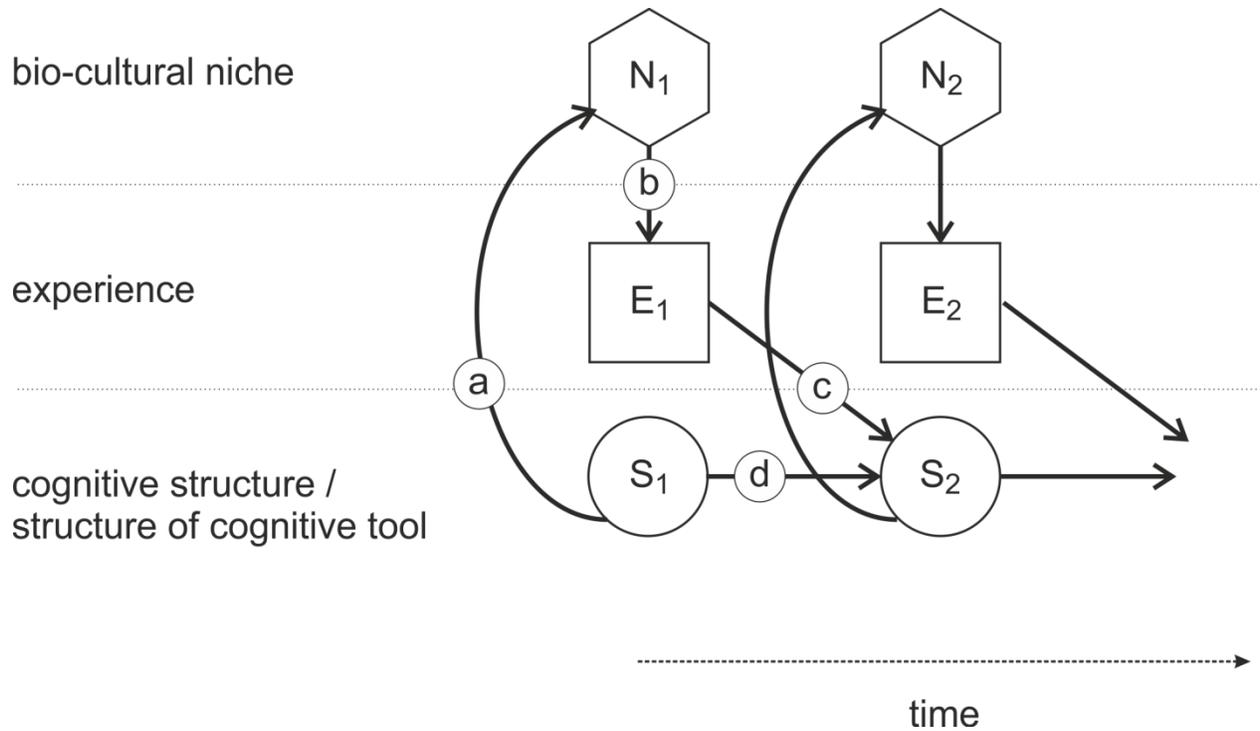
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e 1: The iterative constructivist scheme of change in cognitive structure. A particular cognitive structure or cognitive tool at time 1 is used it to perform an activity in the child's bio- cultural niche (arrow a) which leads to a structure/niche dependent experience (arrow b). There exist causal relationships from the experience at time 1 and the cognitive structure at time 1 to the cognitive structure at time 2 (arrows c and d). Dependent on the properties of the cognitive structure and experience on time 1, influences represented by arrows c and d lead to a transformation of S2 relative to S1, or to maintenance and consolidation of the existing structure such that S1 is equal to S2. This process repeats itself over the time course of development.

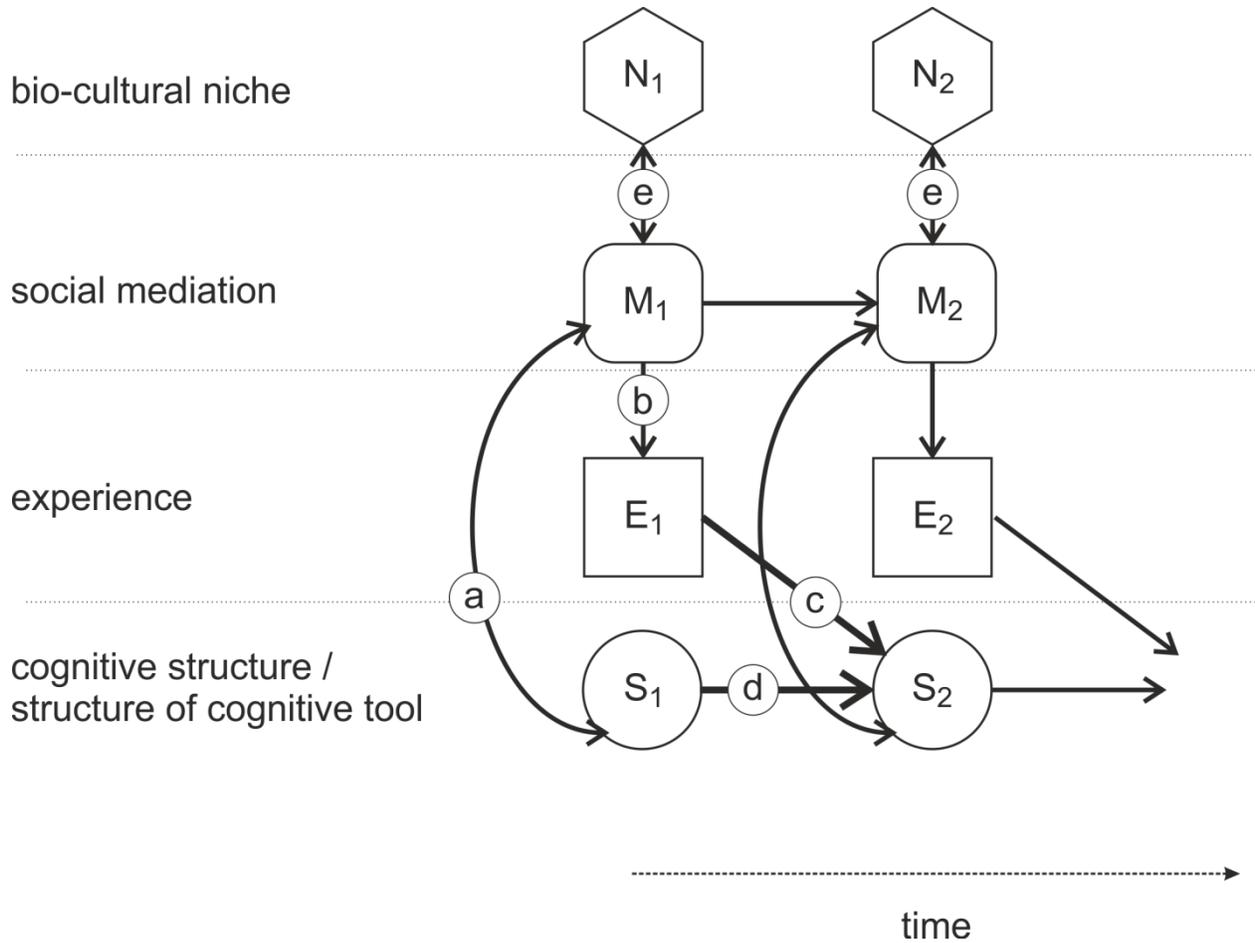


Figure 2: The extended iterative constructive scheme, based on the concept of co-construction. The interaction with the bio cultural niche is mediated by a mediating function, for instance a teacher. The relationship a is bidirectional, representing interaction between the child's cognitive structure and the cognitive tools of the mediator (e.g. a teacher's understanding of the current, context - dependent level of understanding of the child in a problem-solving situation). The interaction with the bio cultural niche is based on the activity of the mediator (relationship E). The activity of the mediator leads to a mediator/cognitive structure dependent experience for the child, and to the causal relationships C and D leading to maintenance/consolidation or transformation of cognitive structure.

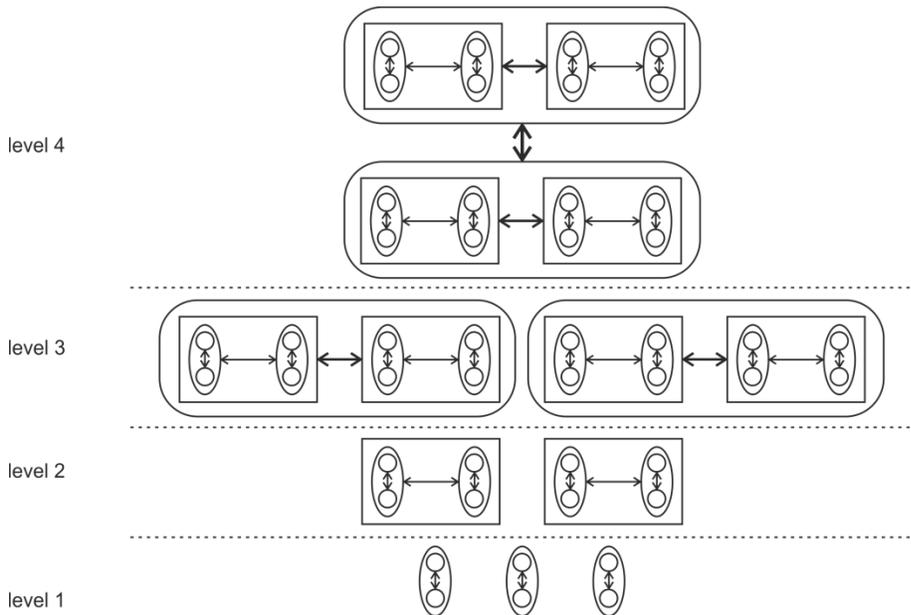
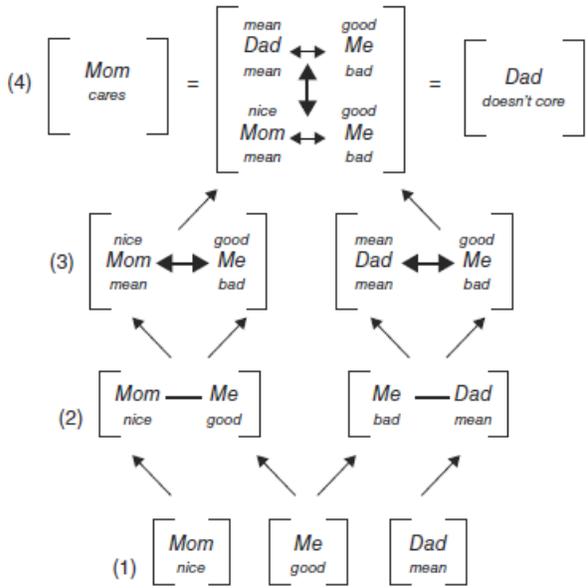


Figure 3: An example of the development of cognitive structure in a child’s representation of parental reactions to its behaving in a “good” or “bad” way, in accordance with neo-Piagetian theory (Fischer, 1980). The emerging cognitive structure represents the development during the age of 2 to 7 years of a dysfunctional relationship with a parent (the father), during the representational tier (stage of development). The bottom level represents single, isolated representations, consisting of simple relationships between persons and properties (e.g. mom is nice). The second level represents relationships between such representations, called mappings (e.g. mom is nice if I am good; dad is mean if I am bad). On the third level, children can represent relationships between such mappings, e.g. mom is nice if I am good, mom is mean if I am bad. On the fourth level, children can represent relationships between systems of underlying relationships, representing the mother’s reaction as fair (she’s nice when I’m good but mean when I’m bad) contrasting this with the unfair reaction of the father (dad is always mean to me irrespective of whether I am good or bad). In neo-Piagetian theory, the description of structure follows very general principles of nested relationships,

which can function in all possible contexts (for instance the child's understanding of family relationships, the child's understanding of basic mathematical operations and so forth). The generalized graph of relationships is represented at the right.

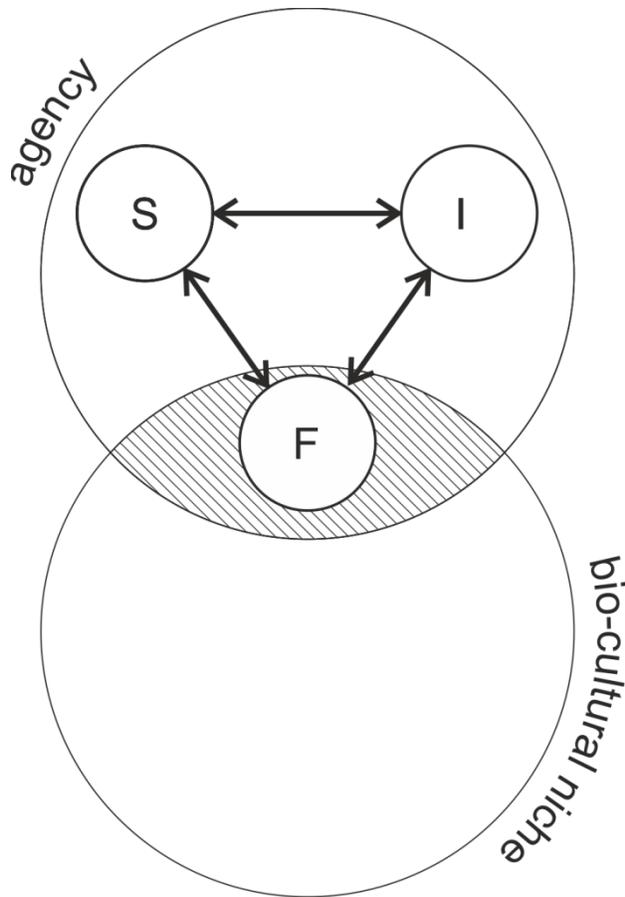


Figure 4: The agency model underlying the constructivist scheme of explanation. Agency implies a reciprocal relationship between cognitive structure (the structure of cognitive tools), intentionality (the structure of intentions to do something, goals and concerns, interests and so forth) and function (activities aimed at realizing one's intentions, given one's cognitive tools and skills, and interaction with one's bio cultural niche, leading to experiences of success or failure). Bidirectional arrows imply that each component influences and is influenced by each other component, both on the short-term timescale of real-time action and on the long-term timescale of development.

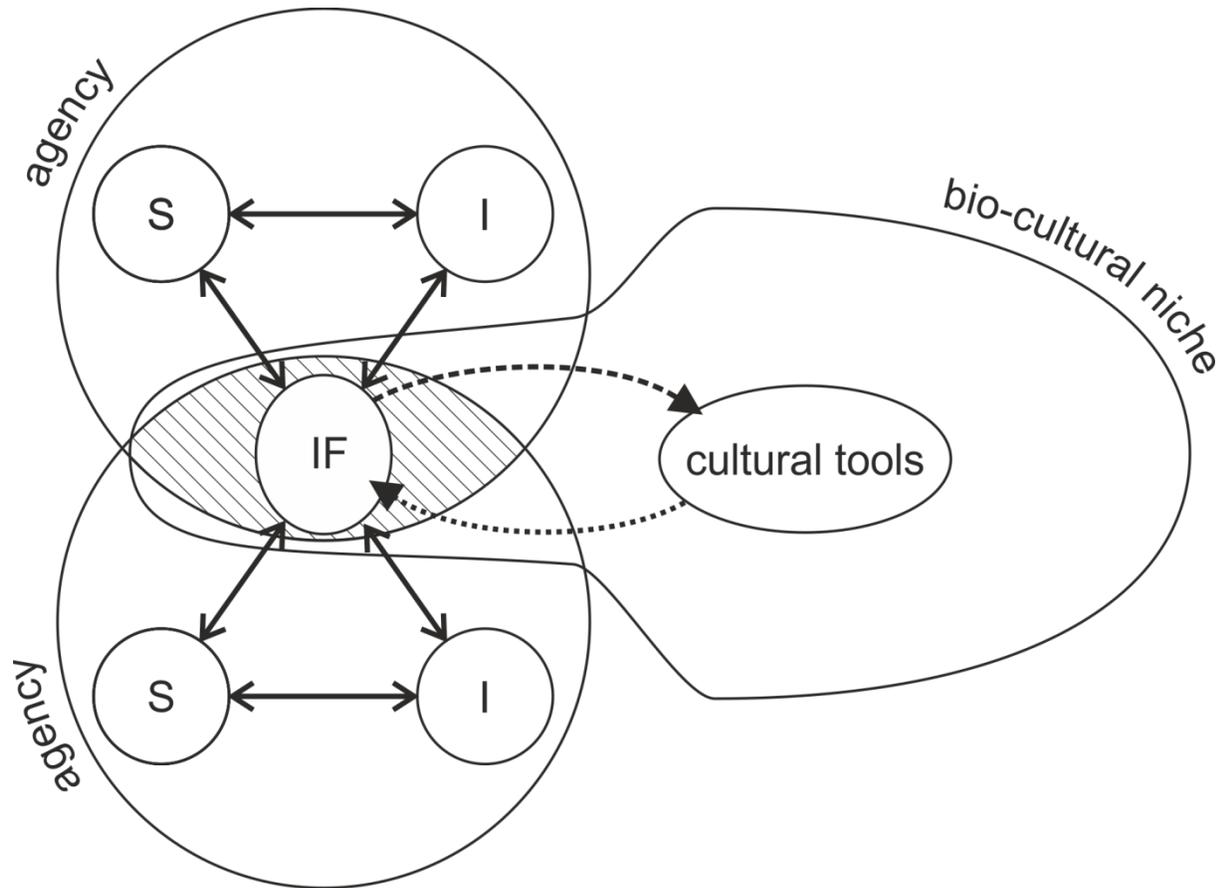


Figure 5: The collective agency model underlying the co-constructivist, or cultural historical scheme of the explanation of development. “Collective” agency is simplified as the interaction between two agents. All agents are characterized by the same structure of reciprocity between cognitive structures, intentionality and functioning. The functioning is now a form of interactive functioning, e.g. joint action is in teaching-learning situations, or the situation of professional work and production. The result of collective agency is the production of cultural tools and artifacts, and interactive functioning of the agents is explicitly determined by the opportunities and constraints provided by these cultural tools. The arrow from interactive functioning to cultural tools is one of professional and material productivity, which is not involved in educational interactions. The latter depend on the influence of cultural tools on the interactive functioning of agents participating in the educational and developmental process, for instance children and teachers. As a consequence of the arrow of production from interactive functioning to cultural tools, the scheme of co-construction not only entails the short-term scale of real-time activity and that the long-term timescale of development, but also the historical timescale of the development of culture and society.

**Interesting websites related to constructivism and to complex dynamic systems in development and education**

<http://www.univie.ac.at/constructivism/edu.html>

Radical constructivism portal

<http://www.univie.ac.at/constructivism/journal/>

website of the journal Constructivist Foundations

[http://sydney.edu.au/education\\_social\\_work/learning\\_teaching/](http://sydney.edu.au/education_social_work/learning_teaching/)

Page from the University of Sydney with links to papers about constructivism and education

<http://www.philosophyofaction.com/>

This website collects tools and information for students, researchers, and teachers interested in the philosophy of action and agency and related topics across various disciplines.

<http://webpages.charter.net/schmolze1/vygotsky/>

website of the Vygotsky project; see also <https://www.marxists.org/archive/vygotsky/index.htm>

<http://archivespiaget.ch/en/index.html>

Jean Piaget archives

<http://www.vonglasersfeld.com/>

Ernst von Glasersfeld was one of the most eloquent defenders of radical constructivism. This website contains lots of texts and clips from his presentations

<http://www.societyforchaostheory.org/>

See the resources for teachers and students and the journal of the society

<https://ejournals.library.ualberta.ca/index.php/complicity>

*Complicity* is an open access (free to all readers), peer-reviewed journal that publishes original articles on all aspects of education that are informed by the idea of complexity (in its technical, applied, philosophical, theoretical, or narrative manifestations). The journal strives to serve as a forum for both theoretical and practical contributions and to facilitate the exchange of diverse ideas and points of view related to complexity in education.