MECHANISMS OF CHANGE

2

TWO

The concepts described above in Section 1 are primarily concerned with the *how* of development, i.e. with the way we can describe the course of change over age. In addition, however, there is also the *why* of development, namely the need to explain the mechanisms that account for change. Children in general become more competent with age; however, age itself is not an explanation but only an index of development, and a rough one at that. It covaries with both biological maturation and social experience, and to sort out the relative influence of these two sets of forces (nature and nurture respectively) has been one of the main preoccupations of developmental psychologists since the emergence of the discipline. Description and explanation are, of course, not wholly separate enterprises: thus the phenomena that an investigator chooses to observe may well be determined by pre-existing theoretical assumptions. Nevertheless, the distinctive aim of explanatory efforts is to incorporate descriptive data in a general theory, in order to give them a wider meaning and to derive certain general principles that can account for the way development takes place, including the conditions that set change in motion, the variables modifying its course and the reasons for individual differences in its nature. Concepts such as the following have been used for this purpose:

MATURATION
Norms of development
ENVIRONMENTAL LEARNING
Observational learning
CONSTRUCTIVISM
Social constructivism
DYNAMIC SYSTEMS
Epigenesis
Self-organisation
CONNECTIONIST NETWORKS

MATURATION
and NORMS OF DEVELOPMENT

MEANING

Maturation is one of the devices that have been put forward to explain the mechanisms of development. It is at the opposite end of the nature–nurture debate to **environmental learning** (see below), in that it stresses innate rather than experiential influences and thus refers to –

> **the sequence of organismic changes occurring in the course of development that are governed by instructions in the genetic code.**

Although applicable to all aspects of development, the concept has been used in the past mainly in relation to motor functions and especially so with regard to infancy and early childhood.

ORIGINS

The assumptions behind maturation have been around for a very long time, and were given explicit recognition by Rousseau (1762) with his assertion that behaviour unfolds according to Nature's inner plan. However, it was not until the first half of the twentieth century that the assumptions were made explicit and incorporated in a formal *maturational theory*. This was very largely due to the efforts of one man – Arnold Gesell, a psychologist and paediatrician, who set out systematically and in the most painstaking detail to plot 'the course, the pattern and the rate of maturational growth in normal and exceptional children' (Gesell, 1928). In this way he aimed to establish **NORMS OF DEVELOPMENT**, that is –

> **the average ages and variabilities for the emergence of new behavioural characteristics.**

Gesell thus provided guidelines for parents and professional workers to enable them to compare the progress of individual children with the norm for their age group, and the test battery that he put together for this purpose (the Gesell Developmental Schedules, see Gesell & Amatruda, 1947) became enormously popular and the forerunner of a series of other, increasingly sophisticated developmental scales.

However, Gesell went well beyond merely collecting descriptive data, in that he also set out to derive various theoretical principles from his observations about the nature of developmental change – principles such as the proposal that development proceeds in a series of sequential changes (see **developmental stages**), and that motor skills emerge according to two directional trends, i.e. *cephalocaudal* (from head to foot) and *proximodistal* (from the centre of the body to the periphery). It was this orderly nature of development above all that convinced Gesell that the changes documented by him are instigated by an intrinsic, biological timetable

that is part of our inheritance and common to all members of the species – that is to say, that developmental changes are maturationally determined. He agreed children need their social environment to realize their potential, but regarded this as essentially a secondary role, in that the sequence, timing and form of emerging action patterns are wholly determined by internal mechanisms regulated by the genes: As he put it:

> The original impulse to growth … is endogenous rather than exogenous. The so-called environment … does not generate the progression of development. Environmental factors support, inflect and specify, but they do not engender the basic forms and sequences of ontogenesis. (Gesell, 1954)

If these ideas are correct it follows that efforts to speed up the acquisition of motor skills by means of deliberate training should be unsuccessful. A number of studies, some carried out by Gesell himself, seemed to show that this is indeed the case: for example a pair of identical infant twins, one of whom was given the opportunity of practising such skills as crawling, climbing stairs and manipulating objects while the other one remained untrained, developed these abilities more or less at the same time. Age at acquisition, it was concluded, must therefore be controlled by an innate timetable and not by environmental factors. And while most of Gesell's work concerned motor development, he was convinced that the same conclusion applies to all other aspects of psychological development. As he put it: 'All his [the child's] capacities, including his morals, are subject to the laws of growth' (Gesell & Ilg, 1943).

CURRENT STATUS

Maturation plays a part in most of the major developmental theories, such as those of Freud, Erikson, Piaget and the ethologists, and moreover its role has received special recognition in certain accounts of language acquisition and perceptual development (Pinker, 2002). Little doubt exists that there is an inborn programme for the appearance of the basic developmental milestones in functions such as motor behaviour and cognition, the timing and rate of which are almost certainly largely laid down in the genes. What is also generally accepted, however, is that Gesell's reliance on maturation as the main, let alone sole vehicle for developmental change is misplaced. There is just too much evidence available to indicate that experience can slow down development, for instance in cases of malnutrition and deprivation (Rutter, 2002), though it is interesting to note that here too a *catch-up* phenomenon can occur whereby the individual returns to the original developmental schedule when restored to a normal environment. Even though the evidence for experience speeding up development is rather more equivocal (Spelke & Newport, 1998), it does seem highly likely that the environment can have a more direct and certainly a much more varied part to play than the merely supportive role which Gesell assigned to it. According to Gottlieb (1997), it is useful to distinguish four different roles which environmental stimulation serves in contributing to development:

- *Inductive*: stimulation that guides behaviour in one direction rather than another. For example, where children are brought up by English speakers they themselves will acquire English as their first language; in Chinese communities, on the other hand, they will learn Chinese.
- *Facilitative*: stimulation that influences when a new function appears. The speeding up or slowing down of motor behaviour by certain experiences is one example.
- *Maintenance*: stimulation that keeps on course already existing structures and functions; without it these would decay and be lost.
- *Canalising*: a narrowing of responsiveness as a result of certain experiences. This is seen in infants' speech perception: the initial responsiveness to the full range of phonemes occurring in all languages gives way at the end of the first year to responsiveness only to those phonemes experienced by infants in their own language community (note that this is a different usage of *canalisation* from the more common one associated with Waddington's, 1957, account).

Such a classification helps in analysing the highly complex interaction of innate and experiential forces, and makes the point that environmental stimulation can serve different purposes at different ages and for different aspects of development.

Even motor functions, the early development of which formed the main arena for maturational theory, are now known to depend on a far more intricate combination of internal and external influences than envisaged by Gesell. The theory was based on the assumption that infants cannot display skills such as reaching, standing and walking till the underlying neuromuscular structures have sufficiently matured to support these behaviour patterns, whereas more recent work has shown that giving children experience of the relevant bodily movements facilitates the development of the structures (Thelen, 2002) (see **dynamic systems**). Thus the relationship of structure and function must be seen as a reciprocal one and not based solely on the effect of the former on the latter. For instance, the more infants are held upright the more likely it is that they practise step movements, thereby stimulating the nervous and muscular structures on which walking depends and thus accelerating the development of walking skills. One of the fundamental tenets of maturational theory is therefore shown to be unfounded, though the concept of maturation itself can still be considered a useful one.

FURTHER READING

Cairns, R.B. (1998). The making of developmental psychology. In W. Damon (Ed.), Handbook of developmental psychology (5th ed.), vol. 1 (R. M. Lerner, Ed.). New York: Wiley. Includes a brief but instructive description of the role of maturation as advocated by Gesell.

Thelen, E., & Adolph, K. (1994). Arnold L. Gesell: the paradox of nature and nurture. In R.D. Parke, P.A. Ornstein, J.J. Rieser & C. Zahn-Waxler (Eds.), *A*

century of developmental psychology. **Washington, DC: American Psychological Association**. One of the best accounts available of Gesell's contribution to developmental psychology.

See also **developmental stages; environmental learning; epigenesis**

ENVIRONMENTAL LEARNING
and: OBSERVATIONAL LEARNING

MEANING

The concept of environmental learning expresses a diametrically opposite point of view to that denoted by **maturation**, namely that –

> **developmental change is brought about primarily by influences in the external environment and can be explained by mechanisms of learning.**

The emphasis is thus placed on experience, and especially so on the actions of adults who shape children's behaviour by means of rewards, punishment and example.

Environmental learning perspectives take three main forms: one based on Clark Hull's classical conditioning account, another on B.F. Skinner's operant conditioning model and the third on Albert Bandura's social learning theory – each distinctive in its view of human nature, its methodology and the mechanisms specified by it. The first of these is now of little more than historical interest while the second has only limited applicability, and it is therefore the third that will be our main focus.

ORIGINS

The belief that learning mechanisms can account for all facets of psychological development goes back at least to John Locke (1693), who asserted that the mind is like a blank slate at birth which needs to be inscribed by experience provided by the child's parents in the form of learned associations and habits. Locke had little empirical evidence to offer for his ideas; however, in the first half of the twentieth century, under the influence of behaviourism and in the course of psychologists' attempts to make their discipline into a formal science, the emphasis on the all-powerful influence of learning experience was taken up again and systematized by Hull and Skinner. The former found a model in the work of Pavlov on the conditioned reflex in dogs: just as animals show a form of learning when initially neutral stimuli are associated with meaningful stimuli (the *classical conditioning* paradigm), so human behaviour too can be extended and transformed by such procedures. A large body of research, much of it on children, came into being as a result of

Hull's proposal, showing that from infancy onwords behaviour can be conditioned and that it is possible to build up or to extinguish particular responses by applying the appropriate techniques. Yet the classical conditioning paradigm turned out to have minimal explanatory value when applied to developmental phenomena, in part because its laboratory-based findings were found to be difficult to generalize to other, real-life contexts, and in part because it became apparent that it is limited to just certain kinds of responses and certain kinds of stimuli – the result presumably of biological constraints operative in each species.

Skinner's *operant conditioning* model has fared rather better. Behaviour, according to this account, is controlled by its consequences: responses that are rewarded are thereby reinforced and become more frequent, whereas responses that are punished will be extinguished from the individual's repertoire. The learning sequence thus starts with the child's spontaneous behaviour, but is completed by whatever the environment supplies in the way of a reply: attention and affection when the child does something desirable, disapproval and anger when the act is considered undesirable. As numerous experiments have shown, this account can explain a range of behavioural phenomena in children, usefully drawing attention to the relationship between a child's actions and the specific ways in which adults respond to them. It is no wonder that the techniques of operant conditioning have been used for purposes of behaviour modification: thus there are claims that bedwetting, thumb sucking, shyness, even autistic symptoms have been eliminated by their use, and for a time the techniques were also applied to instructional methods, seen for example in the development of teaching machines.

Skinner's operant conditioning approach has continued to attract support (e.g. Gewirtz & Pelaez-Nogueras, 1992), yet its 'empty organism' view and neglect of cognitive processes increasingly made other alternatives more attractive, in particular the more widely encompassing perspective of Bandura's social learning theory in its various updated versions (see Bandura, 1977, 1986, 1997). Bandura's basic thesis was a straightforward one: most learning by children comes from watching and imitating other people, and as such has different characteristics from the trial-and-error learning referred to in the conditioning paradigms. **OBSERVATIONAL LEARNING**, as Bandura labelled it, is –

> **the acquisition of new behaviour patterns as a result of watching others perform them,**

and is distinguished by the following characteristics:

- It occurs mainly in social situations, where a model is available that the child can imitate.
- It can involve a whole sequence of responses in one go, as opposed to the bit-by-bit processes described in conditioning accounts.

- It can nevertheless take place very rapidly, often after just one exposure, and was therefore described by Bandura as *no-trial* learning – again in contrast to the gradual shaping entailed in conditioning.
- It does not require any reinforcement, in that responses can be acquired without being associated with a reward directly received by the child.

Bandura's account, like those of Hull and Skinner, was also originally based on the belief that development is fundamentally a matter of environmental learning. Nevertheless, it departed drastically in various respects from its predecessors, and in no way more so than in its assertion that reinforcement is not a necessary part of the learning process. *Vicarious learning*, that is, witnessing the rewards or punishments that follow when another person performs some action, can occur; so can *intrinsic reinforcement*, namely the internal feelings of pleasure or pride the child may experience on completing a task. Thus Bandura broadened the meaning of learning greatly to encompass a range of phenomena that had been neglected in other accounts, but without losing the conceptual and methodological rigour that characterized other learning perspectives.

CURRENT STATUS

The concept of observational learning stimulated a considerable body of research, carried out both by Bandura himself and by other investigators. In particular, a lot of effort went into closely examining the conditions under which observational learning occurs, such as the kind of models whom children choose to imitate; the manner of presenting a model, for example, live or on television; the effect of symbolically coding a model's activity by, for example, verbally labelling it; and the extent to which the child's performance of observed behaviour can be deferred after observation (Bandura, 1977). In addition, the paradigm was applied to various areas of socialization, such as the acquisition of gender roles, the development of prosocial behaviour and the expression and control of aggression.

The flow of such research lessened from the 1980s on, in part because of concern that Bandura's account was not really a developmental one in that it had little to say about age-related changes in behaviour, and in part because the original version of the theory focused on overt behaviour and disregarded cognitive functions. The latter point, however, was met by Bandura in subsequent revisions (1986, 1997), when he set out to identify the mental processes that underlie observational learning, leaning heavily for this purpose on concepts borrowed from information-processing theory. In particular he singled out four groups of such processes, concerned respectively with attention, retention, production and motivation. As he acknowledged, any ability to reproduce some observed act on a later occasion must mean that the child is capable of symbolically coding that act in order to retain and subsequently retrieve it – a skill that comes increasingly to rely on verbal codes rather than on visual images as the child gets older. Similarly, instead of being tied to the observation of just specific instances of others' behaviour children with age become more and more adept at abstracting general rules from these instances and using these to guide their behaviour.

Statements such as these take us a long way from the mechanistic view of environmental learning: people are seen not as passive recipients of external stimulation but as 'self-organizing, proactive, self-reflective and self-regulating' (Bussey & Bandura, 1999). And with this change of emphasis it is also no wonder that Bandura came to refer to his account as 'social cognitive theory' rather than, as before, as 'social learning theory', thereby bringing it more in tune with the present *Zeitgeist*.

FURTHER READING

Bandura, A. (1986). *Social foundations of thought and action: a social cognitive theory*. Englewood Cliffs, NJ: Prentice–Hall. One of Bandura's attempts to move beyond conventional learning theory accounts to a more cognitive, information theory-inspired statement.

Gewirtz, J.L., & Pelaez-Nogueras, M. (1992). B.F. Skinner's legacy in human infant behavior and development. *American Psychologist, 47,* 1411–1422. A fervent plea for the continuing usefulness of Skinner's ideas.

Grusec, J. (1994). Social learning theory and developmental psychology: the legacies of Robert R. Sears and Albert Bandura. In R.D. Parke, P.A. Ornstein, J.J. Rieser & C. Zahn-Waxler (Eds.), *A century of developmental psychology.* Washington, DC: American Psychological Association. Puts social learning theory in its historical context and critically evaluates its contribution to knowledge.

See also **epigenesis; maturation**

CONSTRUCTIVISM
and: SOCIAL CONSTRUCTIVISM

MEANING

The essence of constructivism lies in its view of children as active participants in their own development. Accordingly, the explanation of change does not lie solely in some inborn programmed plan nor in whatever environmental forces the child encounters; instead, children help to determine their own fate by virtue of the meanings they impose on the world.

Constructivism can be defined as –

> **the belief that the mind actively participates in assembling knowledge of the world in the process of interacting with the environment, rather than passively acquiring such knowledge through direct perception.**

Our knowledge, that is, is not a simple mirror image of what is 'out there', but is the result of the mind selecting, interpreting and recreating sensory experience. The end result is thus a product of the interaction of subjective and environmental factors, the subjective factors including such aspects as cognitive level, stored experience, beliefs, motives and temperament. Knowledge acquired from a particular encounter may therefore take different forms in different individuals and in the same individual at different ages.

ORIGINS

The view of the mind as a constructive organ goes back to the eighteenth century philosopher Immanuel Kant, who argued against both the rationalist position that knowledge is derived from innate concepts and ideas and the extreme empiricist belief that the environment is the source of all we know. Instead, he put forward a synthesis of the two views, proposing that the mind is endowed with various structures ('categories of understanding') that enable all human beings to make sense of experience in a certain manner, but adding that these structures will only be mobilized when the relevant experiences are encountered. Knowledge, that is, is acquired during the individual's active interaction with the environment and takes shape as a result of the mind's efforts to assimilate experience (see **cognitive architecture**).

In psychology the idea of the mind as a constructive organ was given prominence by Frederick Bartlett (1932), whose experiments on memorizing showed vividly that the act of remembering is basically a creative process: we rarely recall a message verbatim but rather remember its gist and in doing so transform it in the light of what we already know and expect. It was Piaget, however, who has come to be most closely associated with the idea that cognition is a constructive activity and as such a universal aspect of human development (e.g. Piaget, 1954). For him, knowledge is not a copy of objective reality, accumulated as a result of passively soaking up information. When children try to master their environment they actively select and interpret the information available by bringing to bear upon it what they already know and with the use of whatever cognitive strategies they possess at the time, and in the process they construct successively higher, more sophisticated levels of knowledge. In this sense children are their own agents of development: by struggling to understand their world they come to change that world as they perceive it.

For Piaget the world inhabited by children is largely composed of objects; other people play only a peripheral part in it. Vygotsky (1962, 1978), while also seeing children as actively involved in constructing their knowledge, put a different slant on this process by emphasising the social context in which it takes place. His version has been referred to as **SOCIAL CONSTRUCTIVISM**, which is –

> **the belief that the meanings attached to experience are socially assembled, depending on the culture in which the child is reared and on the individuals responsible for rearing.**

According to this view, the key to cognitive development lies not so much in the child's spontaneous discoveries while exploring inanimate objects as in the interpersonal processes that occur when the child interacts with more knowledgeable people. The attainment of higher intellectual functions is thus seen as essentially a social operation: the child's caretakers serve to pass on cultural values, highlight those aspects of the environment regarded as important, convey meanings to be attached to events, hand down tools for problem solving and support the child's efforts to master these. Development involves internalizing these social interactions – not on the basis of merely absorbing them but by actively processing them with the help of the adult's collaborative efforts. Vygotsky's emphasis on the role of language as used in adult–child dialogues, together with concepts such as **zone of proximal development** and **cultural tools**, has served to throw some light on the mechanisms involved in bringing this about and accounts for the rather greater attention currently being given to Vygotsky's social constructivism over Piaget's biological constructivism.

CURRENT STATUS

The notion that children are active contributors to their own development, cognitive and social, has come to be generally accepted (see **child effects**). The form that this contribution takes varies greatly; it is seen most clearly in the often widely divergent ways in which children interpret and react to identical events and much research has gone into identifying the sources of these differences. Age, temperament, previous experience, emotional state, genetic endowment – these and other individual difference aspects show that the basic proposition of constructivism, that children view reality through a filter of their own making, can be accepted.

The actual process of construction, however, is still not fully understood. Mechanisms advanced by Piaget, such as **equilibration**, **assimilatzion** and **accommodation**, have proved to be too vague to be helpful; their appeal is to intuition rather than to research effort. On the other hand, the prominence given by Vygotsky to the role of language, especially that used in adult–child dialogue, has stimulated a considerable body of further work, designed to show how verbal exchanges can play a part in children's acquisition of the modes of thought customary in their society. This is well illustrated by work on *autobiographical memory* (e.g. Nelson, 1993a; Reese, 2002), which has provided detailed accounts of how young children are helped to give meaning to their past experiences in the course of discussing them with adults, thereby learning what is significant about the past, how to present it in narrative form and what events to incorporate in their self-history.

As to the theoretical underpinnings of constructivism, the anti-nativist position of Piagetian theory has increasingly encountered criticism. According to Piaget, the child arrives in the world with little more than a few sensori-motor reflexes, and by means of mechanisms such as assimilation and accommodation proceeds from there to build up the mental apparatus. A number of writers, collectively known as *neonativists* (e.g. Gopnik & Meltzoff, 1997; Karmiloff-Smith, 1992), while retaining the belief that cognitive development is largely dependent on the child's constructive efforts, consider that more account needs to be taken of the evidence now available

that children are born with a variety of mechanisms that facilitate or constrain the acquisition of certain types of knowledge and that await only the appropriate sensory input to begin functioning. As a result (to quote Karmiloff-Smith), 'young infants have more of a headstart than Piaget granted them'; they are biologically prepared to make sense of the world in certain ways and to acquire particular kinds of knowledge (of human faces, language, space, objects, causation, etc.) that they can subsequently, by their own efforts, build up into more elaborate mental structures. There are disagreements as to the details of this process – just how much is innate and what form it takes (see **domain specificity**) – but the overall conclusion is that constructivism need not by any means be incompatible with nativism, a position that in certain respects takes us back more than two centuries to Kant.

FURTHER READING:

Fosnot, C.F. (Ed.) (1996). *Constructivism: theory, perspectives and practice.* New York: Teachers College, Columbia University. The first part of this multi-authored book provides succinct outlines of constructivism as formulated by both Piaget and Vygotsky, while the remainder examines the application of these concepts to teaching and learning.

Piaget, J. (1972). *The principles of genetic epistemology.* London: Routledge & Kegan Paul. Far from an easy read, but shows why Piaget adopted a cognitive constructive perspective.

See also **child effects; environmental learning; maturation.**

DYNAMIC SYSTEMS

and: EPIGENESIS
SELF-ORGANISATION

MEANING

The term dynamic system is used to refer to –

> **any complex organisation that is composed of multiple parts, each with its own function but also involved in a pattern of reciprocal influences with other parts.**

Neural networks, embryos, mature human beings, families, industrial concerns, economic systems, cultures and galaxies may all be thought of as dynamic systems; the

concept has also been used in physics and chemistry. Their potential for understanding human development has aroused considerable interest in recent years.

The basic principles that characterize the way dynamic systems operate are:

1 *Wholeness*. A system is an integrated whole that is greater than the sum of its parts. Its properties cannot be understood by merely studying the functioning of individual components; attention must also be given to the totality.

2 *Integrity of subsystems*. Complex systems are composed of subsystems, each of which can also be regarded as a system in its own right.

3 *Stability and change*. A system can be open to outside influences. A system may initially resist change in order to maintain stability; where this proves not possible the whole system has to change, even if the external influence affects first of all only one of the parts.

4 *Circularity of influence*. Within a system the pattern of influence is circular, not linear. The components are mutually interdependent; change in one has implications for the others.

The last of these characteristics deserves special emphasis when the systems view is applied to human beings. It is in contrast to the customary unidirectional view of causality which holds, for example, that genes cause structural change, that new structures bring about new functions, that parents direct their children's development, and so forth. Instead, change is always the result of *multiple* influences acting in *joint* fashion and therefore in a *non-linear* manner: new behaviour patterns, for example, can emerge from the interaction of many different parts of the system rather than by one single big push from some specific organismic or environmental source – the *emergent principle*, so-called.

Thus the dynamic systems view refers to the structure and organization of complex entities, but it also denotes a particular view of the way such systems change. When applied to development this is expressed by the concept of **EPIGENESIS**, which refers to –

> **the idea that development involves the sequential emergence of new structures and functions as a consequence of the dynamic interaction among the different components of a system.**

The organism, it is proposed, initially contains only a limited number of basic elements; all later structures and functions are the result of interaction of these original units with each other and with the environment. To understand development it is therefore necessary to shift the focus from the study of isolated elements to the question of how interactions occur, at either the same level (*horizontal* interactions, e.g.

gene–gene, cell–cell or organism–organism) or at different levels (*vertical* interactions, e.g. cell–tissue, behaviour–neural–structure–or organism–environment). Dynamic systems have thus also been referred to as *epigenetic systems* or *epigenetic hierarchical systems* (see Gottlieb, 1997; Gottlieb, Wahlsten & Lickliter, 1998).

ORIGINS

The basic ideas behind dynamic systems have a long tradition, and this applies in particular to the concept of epigenesis. This goes back at least to the nineteenth century, when it was used by biologists as a counter to the belief in *preformationism* – the idea that development is wholly determined by innate structures, that in the fertilized egg there is already an adult-in-miniature (see Kitchener, 1978). It was mainly in the course of the twentieth century, however, that the epigenetic view was taken up by a group of developmental biologists, including such influential figures as Kuo (1967) and Schneirla (1957), and used as a theoretical framework to understand developmental processes in animals, with particular reference to embryological growth and so-called 'instinctive' behaviour patterns. Such behaviour, these scholars argued, does not in fact just appear automatically but as a consequence of multiple internal and external influences that shape the individual's history from conception onwords, indicating that 'instinctive' behaviour is really far more malleable than had previously been believed. A series of experiments, more recently continued by Gottlieb (1997) and mostly involving responses in birds such as pecking, vocalization and movement patterns, provided empirical support for these assertions and for the usefulness of adopting a systems view of mutually interacting influences to account for behavioural change rather than one relying simply on maturational push.

The person generally credited with having first formalized the general principles underlying dynamic systems and demonstrated their wide applicability is von Bertalanffy (1933, 1968). An experimental embryologist himself, in his General Systems Theory he crossed the boundaries between biology, chemistry, physics, psychology, sociology and economics by arguing that the functioning of any multipart dynamic whole could be explained in terms very different from those of the customary 'machine theory', as he called it, which reduced everything to the properties of individual components and which therefore resulted in the hunt for ever-smaller units, whether in chemistry or in psychology. A system model, on the other hand, sees the essence of the whole to lie in the relationship of its parts, and it is this aspect, von Bertalanffy believed, that should be the focus of any study designed to understand the ability of the system both to maintain equilibrium and to bring about change. Systems thus have properties in their own right that cannot be deduced from the properties of their components; what is more, in a hierarchically arranged system each level is distinguished by its own properties: what happens at one level may not therefore explain what happens at another level – a child's motor action is not explained by reference to the constituent cells.

Von Bertalanffy's ideas received recognition among scientists concerned with many different kinds of systems, and a Society for General Systems Research was founded in

1954 to further his proposals and establish systems work as a distinct discipline. In psychology these views were somewhat slow to catch on: the prevalence of learning theory in particular ensured that a unidirectional way of thinking about causality continued to prevail. It is only comparatively recently that psychologists, including developmentalists, have begun to explore the usefulness of such an approach.

CURRENT STATUS

In recent years attention has focused on what is generally regarded as the essence of systems, namely that they are self-organizing. **SELF-ORGANIZATION** means that –

> **new structures and behaviour patterns emerge spontaneously in the course of development, without explicit instruction either from within the organism or from the environment, through processes intrinsic to the system itself.**

Such a view entails a marked shift of paradigm with respect to developmental issues. As Cairns (1998) has put it, the answer to the question 'What directs development?' is, simply stated, 'The organism'. Instead of looking to maturation or learning or even some combination of the two, systems theorists believe that it is a fundamental characteristic of living things for their constituent processes to change themselves. New patterns, that is, emerge spontaneously, without any explicit instruction from within the organism or from the environment. Thus, as a result of a series of small changes among the constituent parts a major reorganization in the system as a whole may be brought about, and following each such reorganization the organism will become increasingly complex and ordered. Self-organization, it is maintained, is thus the real source of developmental outcome.

Much of the research inspired by a systems view has been concerned with motor functioning in infancy, largely thanks to the efforts of Esther Thelen and her colleagues (Thelen, 2002; Thelen & Smith, 1994). As her work has demonstrated, a seemingly unitary behaviour pattern such as stepping is in fact composed of many subunits developing at different rates and sensitive to different organismic and environmental influences. Behavioural change can occur only when the system as a whole is ready to proceed to a new developmental level; locomotor development is thus a multidimensional process, dependent on the co-action of central nervous structures, bodily biomechanics and environmental supports and constraints. To explain such a development no one cause can be evoked; the baby's existing action patterns, the neural structures available, the nature of the task and its environmental setting, the child's past experience and present motivation – all play a part, and it is their interaction as a total configuration that brings about the eventual change.

Various other aspects of children's behaviour have also been investigated from a systems point of view, such as language (Smith, 1995), cognition (van Geert, 1993), emotion (Lewis & Granic, 2000), attachment (Laible & Thompson, 2000),

dyadic communication (Fogel, 1993), infants' behavioural states (Wolff, 1987), psychopathology (Granic & Lamey, 2002) and antisocial behaviour (Granic & Dishion, 2003). However, it is in relation to family functioning that a systems perspective has gained most acceptance. A family is in many respects a particularly clear example of a dynamic system: it can be conceived as a three-level organization in that: it is an entity in its own right, which is composed of two kinds of subsystems, namely individuals and the relationships between the individuals; it has properties that cannot be deduced from the properties of the components; and it is characterized by a highly complex, circular influence process that ensures that a change in any one of the components will have repercussions for all other components and for the system as a whole. Simple linear cause-and-effect statements cannot therefore do justice to the reality of the family situation; events such as marital conflict, the birth of another child, a father's unemployment or a mother's death have consequences that, according to a large number of studies, can more easily be understood if seen from a systems point of view (Cox & Paley, 1997).

There is still doubt in the minds of many regarding the extent to which all aspects of human behaviour and development can benefit from such an approach (e.g. Aslin, 1993). Others are more enthusiastic (e.g. Lewis, 2000), and there is certainly no question that the number of psychological functions to which the concept has been profitably applied is steadily increasing. In particular, a dynamic systems view is seen as having the potential of bringing unity to a field characterized by a great many mini-theories: it has the advantage that it includes many aspects of development and many levels of analysis, and so can provide a single explanatory framework applicable to a diversity of phenomena. The fact that the principles on which it is based can be extended to all types of complex organisation is seen as an additional asset.

FURTHER READING

Gottlieb, G. (1997). *Synthesizing nature–nurture.* Mahwah, NJ: Erlbaum. An informal account of the thinking and research underlying the idea of dynamic systems and associated concepts.

Lewis, M.D., & Granic, I. (Eds.) (2000). *Emotion, development and self-organization: dynamic systems approaches to emotional development.* Cambridge: Cambridge University Press. A collection of reports spanning a considerable range of work on developmental topics.

Thelen, E. (2002). Motor development as foundation and future of developmental psychology. In W.W. Hartup & R.K. Silbereisen (Eds.), *Growing points in developmental science.* Hove: Psychology Press. Useful as a succinct introduction by a leading dynamic systems researcher.

See also **connectionist networks; constructivism**

CONNECTIONIST NETWORKS

MEANING

Also referred to as *artificial neural networks* or *parallel distributed processing*, connectionist networks are –

computer models loosely based on neural information processing, aimed at specifying the dynamics of cognitive processes and testing out models of development.

Connectionism is based on the belief that the traditional approach to cognition, as represented by information processing theory, is misleading in its emphasis on the *serial* processing of data. Instead, connectionist networks are seen as intricate systems of simple units (or nodes), generally arranged in layers serving such specific functions as input, processing and output, which handle information *in parallel* by means of a vast net of interconnections. While the units themselves merely fire or do not fire impulses and have no further meaning on their own, the total pattern of excitation created in the network by their activity can give rise to highly complex output patterns simulating human behaviour. Thus, instead of viewing cognition in terms of the manipulation of symbols as is common to other approaches, connectionists see it as a network of simple interconnected processing units functioning as a dynamic system which, supplied with some input, will spread a pattern of excitement and inhibition that accounts for mental activity. Connectionist modelling provides a computational methodology aimed at demonstrating this process and a means of evaluating alternative hypotheses concerning learning and development.

ORIGINS

While *connectionism* as a term goes back to Donald Hebb's writings in the 1940s, connectionist ideas did not become formalized until the mid-1980s. Two publications, edited by Rumelhart and McClelland (1986) and McClelland and Rumelhart (1986), are generally taken to be the point when connectionism started to be taken seriously. These two volumes spelled out in detail the principles and methods underlying the study of parallel distributed processing, and also demonstrated their applicability to specific aspects of cognition. For example, in one of the contributions to these volumes Rumelhart and McClelland developed one of the earliest connectionist models in order to investigate how children might be able to learn the past tense of English verbs and to differentiate between regular and irregular verbs. The computer model used by them was a fairly unsophisticated one, yet they were able to train it to perform in a manner similar to language-acquiring children and so demonstrate that a child's learning can occur in a relatively simple manner without the use of any rule-based mechanisms. They thus not only found a

simulation technique for profitably investigating aspects of human behaviour but also showed that this could lead to new insights into the processes that bring about developmental change.

It subsequently became apparent that Rumelhart and McClelland's account was flawed in a number of ways and that their generalization to real children was in some respects unjustified. Other investigators in later years set out to improve on their methodology; however, the inspiration to use connectionist network modelling had been provided and, though initially slow to catch on, the technique has recently attracted interest from an increasing number of investigators.

CURRENT STATUS

Connectionist modelling has now been applied to a considerable range of topics, including problem solving, reasoning, memory, object permanence, vocabulary growth and syntax acquisition (see Elman, Bates, Johnson, Karmilott-Smith, Parisi & Plunkett, 1996; Plunkett, Karmilott-Smith, Bates, Elmon & Johnson, 1997 for details). As a consequence, the nature of connectionist networks and the uses to which they can be put have become greatly clarified.

To summarize this work: connectionist networks can be computer simulated in a range of different forms and degrees of complexity, depending on the purpose of the investigator. All, however, contain certain basic ingredients, namely a large number of simple processing units (idealized brain neurons) that are interconnected via a network of pathways (like synapses). The most common form of network employed so far by investigators interested in modelling human behaviour involves the arrangement of units in three layers serving input, processing and output functions, respectively modelling sensory, central and motor processes. While units within any one layer are not interconnected, each unit at one layer is connected with every other unit at the next layer, enabling the processing of information to be carried on in parallel throughout the network.

Networks can be constructed to incorporate various constraints, representing individuals' inborn or age-related characteristics, and then be given 'tasks' in order to investigate the nature of the learning processes adopted by the system. Learning is said to occur as a result of changing the *weights* (i.e. strengths) of the connections between units in the different layers; during the learning process the weights change constantly until finally, as a result of the network comparing the pattern produced with some criterion (an external one such as the demands of a teacher or an internally generated goal), the connection strength becomes stable and learning is said to have been achieved. The assumption is that this represents a child's real-life experiences and provides insight into the precise characteristics of learning and developmental processes. Thus, by building in different initial constraints or by trying out various input–output patterns, all of which need to be precisely specified in constructing the computer model, it is possible to explore a range of different hypotheses as to the nature of developmental change (for detailed accounts see Mareschal, 2000; Plunkett, 2000).

Among the insights into the general nature of development claimed by connectionist workers the following stand out:

- Networks demonstrate stage-like changes in the nature of learning, but these are not the result of some new, qualitatively different mechanism suddenly clocking in as Piaget believed, but are brought about by a series of small, gradual increments in learning which, when some particular point is reached, can all at once lead to a drastic restructuring of overt behaviour. New behaviour, that is, does not necessarily mean new mechanisms.
- The acquisition of complex behaviour patterns in the course of development need not depend on the potential availability of complex learning devices from the start of development. These can *emerge* from the interaction of even a quite immature organism with a rich learning environment: it is the interaction that takes a complex form rather than the starting state of the organism.
- Some relatively simple networks are fixed in their structure from the beginning of life on, but others are *generative* in nature in that they change their structure as a result of learning experiences. They do so by creating additional hidden units, and in this way become capable of coping with tasks of increasing difficulty.
- Connectionist networks have been constructed that model a range of developmental disorders, including autism, dyslexia and specific language impairments. These show promise of throwing new light on the mechanisms responsible for different forms of psychopathology, challenging previously held assumptions and accepted views (for some further details see Thomas & Karmiloff-Smith, 2002).

As indicated, the most important point about connectionist networks is that they involve parallel as opposed to serial processing of information by the individual. For one thing, this is much more in keeping with what is now known about the functioning of the neural system; for another, it draws attention to the fact that connectionist networks share certain fundamental properties with **dynamic systems** – indeed, according to some writers they represent one particular type of such a system (for discussion see papers in a Special Issue of *Developmental Science*, introduced by Spencer & Thelen, 2003). Both approaches emphasize *non-linear* causation: connectionist networks too, that is, are based on the assumption that the causation of behaviour is often not as obvious and straightforward as such earlier developmental theories as the various learning approaches believed (see **environmental learning**) – largely because the influence process is generally based on the joint functioning of multiple forces rather than on the pull–push model of linear causation. In addition, connectionist networks are like dynamic systems in being self-organizing in nature (see **self-organization**): changes in their make-up are not necessarily brought about by the action of external forces but by the network modifying itself spontaneously in the course of functioning. The two approaches have different histories and different vocabularies, but they share core assumptions and may well merge in the near future.

There has been something of a boom in research on connectionist networks in recent years as their potential for exploring ideas about development has become increasingly evident. This does not mean, however, that the approach has been without critics. Thelen and Smith (1994), for example, list a number of reservations, in particular the fact that connectionists do not acknowledge the diversity of brain structures and instead treat all processing units as homogeneous. Above all, however, one must bear in mind that the networks are not 'real' but simulated, having been put together by computer modellers and are for the most part of a degree of complexity vastly less than that of biological systems. Thus, the observation that a network can be trained to perform a particular task does not mean that children necessarily behave in the same way but only that they *may* be able to do so.

FURTHER READING

Elman, J.L., Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996) *Rethinking innateness: a connectionist perspective on development.* Cambridge, MA: MIT Press. A book that has rapidly become a classic – not easy but foundational.

Mareschal, D. (2000). Connectionist modelling and infant development. In D. Muir and A. Slater (Eds.), *Infant development: essential readings.* Oxford: Blackwell. An overview of connectionist thinking, meant as an introduction to the topic.

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See also **dynamic systems; self-organization**