**The allosteric learning model and current theories about learning**

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Research on learning is currently converging towards several key findings. These specifically highlight the limits of both traditional teaching practices and of several innovations (active, non-directive, discovery methods). Studies show that even when teachers conscientiously cover the entire curriculum knowledge does not necessarily 'get across' to learners.

Concepts, new ways of thinking, cannot be learned by direct teacher-student transmission. In fact, learner thought processes are not passive recording systems. Before a topic is treated in class, each learner already has various questions, ideas, references and habits (which relate to that topic) in mind. In other words, he or she manipulates a specific kind of explanation called conception. Conceptions shape the way all learners (children or adults) decipher information. Knowledge construction relies on mobilized conceptions through which learners interpret data they receive and potentially develop new knowledge. Each time a model is understood or a concept is mobilized the learner's mental structure is completely reorganized. Therefore, learning is not the result of simple transmission processes, of the one-way channels from teacher to student that are commonly observed. Likewise, although learner actions might be necessary, these are not always sufficient.

The appropriation of knowledge results from conception transformation processes for which the learner, he or she alone, must take the leading role. Acquiring knowledge is the result of an elaboration activity during which learners compare new information with mobilized knowledge and produce new meanings, which are more appropriate Afor answering their questions.>> >The main theories on learning are all quite limited in this respect. Therefore, to understand learning processes we must develop a new model, which integrates the parameters, which challenge mobilized conceptions. One attempt was initiated at the LDES in 1987 (Giordan and De Vecchi 1987) and since 1988 it has been successfully refined (Giordan 1988). The model is now known as the Allosteric Learning Model (Modèle d'Apprentissage Allostérique, in French). Although it remains imperfect, the model has the advantages of defining the issue, of explaining the main characteristics of learning, and of allowing predictions. Finally, and this is why it has become quite popular, the model provides practical tips about which educational environments are likely to facilitate learning. It allows us to infer heuristic hypotheses related to specific educational projects in schools or in the media. Below, we first briefly situate the Allosteric Learning Model amidst other current theories about learning. Then, we provide details about our model and highlight its relevance.

## 1. Current Learning Theories

Education is still very much the result of experience and empiricism. However, when investigating current methods we can easily identify several more or less implicit axioms, which underlie both theory and practice. These basic postulates are very diverse, and this makes them difficult to categorize; luckily, there are several publications that can help us classify these postulates while avoiding undue schematisation.

The analysis we propose in this paper is based on the three most common discriminants that appear in the literature: knowledge, the student, and society. This allows us to sort multiple approaches into ten theoretical perspectives situated along three spatial axes:

-Knowledge Axis: academic, technological, behaviourist and epistemological theories;

-Society Axis: soAcial, socio-cognitive and psychosocial theories;

-Learner Axis: humanist, genetic and cognitive theories.

To be comprehensive, we also cite spiritualist theories since they are regaining some importance at the turn of the millennium.

**1.1. Spiritualist theories**

A very old perspective on learning has been renewed during the past decade: 'spiritualist', 'transcendental' or 'New Age' approaches. Historically, these were to be found within religious or metaphysical frameworks. Oriental philosophies and religions have always fed into the debate on education. In particular, they propose that each person must liberate himself from what is known in order to rise beyond it. Under certain conditions, students can reach 'superior' levels of knowledge by a series of initiatic steps. Nowadays, such ideas are being redeveloped, together with the renewal of religious beliefs, and particularly inspire individuals who are preoccupied with the meaning of life. Each person must master his spiritual or material development by using inner energy and canalising it into activities such as meditation, contemplation or autosuggestion. Necessary 'energy' always comes from within the learner and may be presented under various guises: 'God', 'Tao' , the 'Invisible', 'Divine Energy', etc. The main values within this educational perspective are 'Goodness', 'Justice', the 'Other' and 'Beauty'. The educational theories of Harman (1974), Krishnamurti (1970), Maslow (1968, 1971), and Leonardet de Ferguson are all part of this movement.

American transcendentalism, whose pioneers were Emerson (1983), Thoreau and Fuller, as well as metaphysical theories have also contributed to the approach. Finally, within the spiritualist movement, numerous teaching practices have been simultaneously developed, ranging from relaxation to suggestopedia. The movement also borrows from other educational approaches emphasizing, for example, the importance of individuals, orA the acquisition of learning methods, etc.

**1.2. Academic theories**

The theories we call 'academic' have also been described as 'rationalist', 'realist', 'essentialist' or 'classic'. To date, they are the most frequently applied theories in educational systems. They focus on the transmission of knowledge (Bloom 1987): everything is centred on the facts that are to be taught, on how the knowledge is to be mastered by teachers or other communicators. Such pedagogy is based on the presentation of factual

knowledge by teachers (Snyders 1973, Houssaye 1987). The teacher's role is to transmit a specific content and the student's role is to absorb it. Dogmatic or frontal teaching is encouraged. Sometimes, such logically constructed courses are based on illustrations (models or photographs) or experiments which confirm the teacher's words. Excellency requires well-structured, progressively presented ideas, and the main effort is linked to study and memorization. Two tendencies coexist within the academic perspective: traditionalists and generalists. The first highlight classic contents, independently of contemporary cultures or social structures (Hutchin 1953, Pratte 1971, Adler 1986, Finkielkraut 1988, Domenach 1989). The second promote more general contents and emphasize the abilities to think critically, to adapt, to keep an open mind, etc. (Hamel 1989); these qualities are thought to be the inevitable consequences of well-structured lessons.

### 1.3. Technological theories

Technological or 'systemic' theories generally insist that the message of a lesson ought to be transmitted using appropriate technology. However, 'technology' is understood in a very broad sense, involving both concepts from communication theory (broadcaster, receptor, codes), as well as specific didactic materials for the communication and treatment of information.

Historically, the emphasis has been on visual (panels, slidAes) and audio-visual (films) media. Today, similar arguments are found in favour of television, video, tape recorders, CD-roms and computers (Lockard et al. 1990, Wager et al. 1990, Lapointe 1990). The key idea is as follows: by decomposing a message into striking visual elements students will automatically adhere to it by some kind of impregnation (Tickton 1971). Nowadays, most approaches rely on the computer's 'impressive' abilities (Kearsle 1987, Lawler 1987, Solomon 1986) since it can easily generate multiple sources of information (images, sounds, writing, etc.) and enables learners to witness simulations (Papert 1980).

The most recent approach focuses on computerized learning environments and interactive software (Suppes 1988, Bergeron 1990), which are gaining importance with the development of multimedia and hypermedia. The objective is to create situations requiring concepts and artificial intelligence in order to simulate real life or laboratory experiments. CD-roms, which combine incredible quantities of images and audio comments, are also frequently promoted.

### 1.4. Behaviourist theories

Behaviourist theories arise from Watson's work; they are also called 'programmed' or 'Skinnerian' learning (Holland and Skinner 1961, 1968). These theories are hostile to introspection and extend research on conditioned reflexes, based on stimulus-response mechanisms, and on the ideas of conditioning and reinforcement. For learners, reinforcement means knowing that their answer is correct.

However, for reinforcement to be effective it must apply to small quantities of information. Behaviourist theories suggest teachers should divide each topic into small units of knowledge; each unit is then the target of specific exercises.

Behaviourism has had a lot of influence on professional and technical training. In schools, it is has led to programmed learning on the one hand (Landa 1974) and to objective-driven pedagogy on the othAer (Bloom et al. 1956, Mager 1962, Krathwohl 1964). The consequences of these ideas are still present in numerous curricula, especially in English-speaking countries, as well as in some educational software materials.

**1.5. Epistemological theories**

This perspective, which is still being developed, is based on the idea that a better awareness of knowledge structures, and of the methods which are likely to produce them, should facilitate teaching. Thus, the starting point is always the construction of knowledge at an epistemological or historical level. Kuhn (1970) and Popper's (1961) publications in English-speaking countries, and Bachelard's work (1934, 1938) in French-speaking countries are the main foundations for these theories (ideas which relate to paradigm shifts, refutability, epistemological obstacles).

These theories have resulted in various educational practices. For example, Bachelard's followers base their teaching on the history of science in order to pinpoint obstacles and explain each obstacle's nature (Canguilhem 1974, Rumelhard 1986). Then, the teacher prepares specific situations in order to overcome or avoid those obstacles. There are various ways of implementing epistemological ideas in teaching, however. Often, teachers encourage students to express their conceptions, and then they explain new knowledge in the light of what students have said (Bednarz 1989).

Nowadays, this approach is becoming systemic. Based on the ideas of Von Bertanlaffy (1967) or Morin (1977), all knowledge is understood as a system. Educational implications are discussed in publications by De Rosnay (1975), Pocztar (1989) and Dick and Carey (1990), among others.

**1.6. Social theories**

Social theories of education insist on the social or environmental determinants of educational life and highlight their objective dimensions. The favourite topics of these researchers are social class divisions, sAocial and cultural heredity, the social background of students and elitism. More recently, the focus has been on environmental issues, the negative impact of technology and industrialization, the degradation of life on Earth, etc.

These theories were mainly developed in the 1960s and 1970s. In particular, they criticized traditional teaching practices and institutions (Vasquez 1967, Lapassade 1967, Lourau 1970, Lobrot 1972, Oury et al. 1971). According to these theories the educational system should have the primary mission of preparing students by helping them overcome socio-cultural handicaps. Instead, current institutions seem to do the opposite: they reproduce social and cultural inequalities and ignore what is going on outside school.

Also, social theories focus on the changes education should undergo to improve its relation with society (Freire 1974). These transformations range from critical analyses of the social and cultural bases of education (Lapassade 1971, Lobrot 1972) to radical propositions of social change (Illich 1970). Further, certain theories dwell on the analysis of social interactions (Grand'Maison 1976). Others focus on the cultural bases of education and claim that an essential cultural dimension should be included into teaching practices (Oury et al. 1971). Thus, these theories are very different from the cognitive movement which is preoccupied by the exact nature of knowledge processes.

**1.7. Socio-cognitive theories**

Instead of emphasizing society as a whole, this theoretical approach highlights the cultural and social factors that intervene in the construction of knowledge. Several variations of these theories exist: some focus on the social and cultural interactions that shape the evolution of a person in society; others investigate the act of learning and emphasize cooperation for the construction of knowledge. The latter promote cooperative pedagogy in order to make students aware of the impoArtance of cooperative work (Augustine et al. 1990); they insist on all possible interactions between learners and group projects are recommended (Brandt 1990, Kagan 1990).

These authors also challenge the domination of cognitive theories in research (Bandura 1971, Joyce and Weil 1972). They point out that there are problems with an excessively psychological vision of education and highlight the social and cultural conditions of knowledge (Bandura 1986, Lave 1988, Johnson and Johnson 1990). This movement is currently very dynamic>> >in the United States (Slavin 1990, Johnson and Johnson 1990) and in Canada.

**1.8. Psycho-cognitive theories**

Psycho-cognitive theories are essentially focused on the development of cognitive processes in learners, such as reasoning, analysis, problem solving, etc. However, they emphasize the interactive parameters that take place within the class-group (McLean 1988).
These theories are closely related to those described above (1.7.), since they dwell on the social and contextual aspects of learning and are based on findings from psychosocial research (Moscovici 1961, Doise 1975, Perret-Clermont 1979).
These theories focus on the interactions between individuals while learning (Doise and Mugny 1981, Carugati et al. 1985, Gilly 1989). Depending on the author, such interactions may be called 'socio-cognitive conflict', 'group practice', or 'opposition of representations'. The confrontation between different representations is of key importance since it allows learners to take a step back away from their conceptions and overcome obstacles (Perret-Clermont 1988).

**1.9. Humanist Theories**

Humanist theories, which are also called 'personalist', 'libertarian', 'pulsional', 'free' or 'open' base themselves on individual learners. Depending on the author, the notions of 'self', 'freedom' or 'autonomy' may be highlighted. These theories insist on each studentA's freedom, desires and motivation to learn.

The most famous advocate of these theories is Rogers (1951, 1969). Learners, often called 'clients', must manage their own education by using their inner potential. Teachers only play a facilitating role and must help learners strive to continually actualise themselves (ParÈ 1977). Following the development of these ideas, many 'open', 'alternative' or 'non-directive' schools were founded in the 1960s and 1970s, inspired by perspectives on the integral development of children (Kirschenbaum and Henderson 1989).

## 1.10. Genetic theories

Building upon 18th century philosophical ideas (Leibnitz 1704, Kant 1781), these theories assume that a pre-existing cognitive structure is to be found within each learner. The structure mainly 'develops' by 'maturing' through a series of stages; it facilitates memorization and is an anchor for newly acquired data.
Numerous psychologists adopted this idea at the beginning of the 20th century but it gained considerable importance after the end of the Second World War and up to the 1970s. The most frequently cited authors are Wallon (1945), Kelly (1962), Gagné (1965, 1976), Bruner (1986), Piaget (1966, 1967) and Ausubel et al. (1968).

The latter have had the most impact on teaching practices during the past two decades. For example, Gagné (1965) distinguishes between 'concrete' concepts on the one hand, which are learned through observable properties and lead to the identification of classes using their representatives, and 'defined' concepts on the other hand, which are learned through definitions; these are also called relational concepts. According to him, learning at school first occurs in the language of concrete concepts, which are progressively replaced by defined concepts. Thus, the concrete concept 'round' is transformed into the defined concept 'circle', i.e. 'curve whose points are all equidistant from a fixed pAoint called center'. When learning defined concepts students express their knowledge by referring to the definition and demonstrating its use.

Ausubel (1968) considers that everything has to do with integration; this is facilitated by 'cognitive bridges that make new information meaningful by referring to pre-existing global mental structures. In his conceptual framework new knowledge can only be learned if three conditions are fulfilled. First, more general concepts must be available and gradually differentiate during learning. Second, 'consolidation' must take place for current lessons to be mastered: new information cannot be presented to students if previous information has not yet been understood. If this condition is not respected, all learning may be compromised.
Finally, the third condition involves 'integrative conciliation': pinpointing similarities and differences between old and new knowledge, distinguishing between them and, if needed, resolving contradictions; this automatically leads to remodelling.

The most frequently cited genetic model was developed by Piaget. It is based on 'assimilation and accommodation', and more particularly on the tight link between them, which led him to propose the concept of 'reflecting abstraction' ('abstraction réfléchissante', in French). Students enter data from the outside world into their own cognitive organization. The way new information is treated depends on prior knowledge, i.e. it is assimilated. In return, there is accommodation, i.e. existing thought schemes are transformed depending on the new circumstances. Thus, learners must tie new information to what is already known, graft it upon notions depending on schemes available to the subject. Quite often, these are reorganized by the new data.

Finally, we should mention Vygotsky (1930, 1934), the founder of Soviet psychology who was isolated throughout Stalin's era and was only rediscovered in 1985 by the science of eAducation. Based not only on psychology but also on linguistics, grounded in experimental studies and using an original method (the analysis of basic units), Vygotsky's research focuses on words as the units of thought, on the successive stages of verbal and intellectual development from each child's first utterances through to adolescent and adult concepts via syncretism, 'thinking in complexes' or 'inner speech'.

**1.11. Cognitive theories**

Cognitive theories have diverse origins: they are an extension of animal psychology (Tolman, Krechevski, Brunswik), genetic psychology, and social psychology (Lewin, Asch, Heider, Festinger), but also of Gestalt psychology and neurophysiology. They were established in the 1980s, via research on information. This field is currently undergoing rapid development and is penetrating all areas of psychology to the point of encompassing all prior approaches. Its global aim is to construct an understanding of 'what happens in the head' of a person who's thinking (motor activities, perception, memorization, comprehension, reasoning).

In particular, cognitive psychology tries to unravel the mechanisms surrounding the reception, treatment (mental image, representation), storage, structuring and use of information (Anderson 1983, Gardner 1987, Holland et al. 1987). The concept of communication is key. Complex cognitive activities are treatments of integrated representations. These explanations have not yet stabilized; they are still heterogeneous and specified in subfamilies of local models (Rumelhart et al. 1981), which have different details but remain nonetheless related at the level of general principles.

An extension of these theories is research on artificial intelligence, and connectionist theories emerging from neurobiology that suggest cerebral bases for the main cognitive functions. Nowadays, all of these theories have reached a turning point; narrow links are being established with bioloAgy (not only with the nervous system, since the immune system also exhibits learning phenomena), with linguistics, with semiology, with information technologies, with system experts, with sociology (epidemiology of representations) or with cognitive ecology. Cognitive theories have proven to be useful for decision-making and management, and for the production of teaching software. However, within the educational system, the implementation of these new approaches has not really taken place, even though some effective applications have been discovered (related to the left or right side of the brain, or to neural connectionism).

## 2. A few critical comments

All of the theories described above require a detailed analysis in order to determine their overall potential and limitations with regard to educational and cultural practices. However, we shall only briefly pinpoint some of their shortcomings below. These may be general or specific. It is out of the question to discuss details within the scope of this paper: that is the basis of a future project, which awaits the 'decantation' of the most recent cognitive theories.

### 2.1. General comments

Apart from certain cognitive approaches, learning is not the original focus of any of these theories but is considered, at best, as a potential side effect. Their focus may be, for example, the 'natural' construction of knowledge (epistemological theories), social functioning (social theories), or general development processes (genetic theories).

Let us, for example, consider genetic theories: they avoid both the contents of learning (object of knowledge) and its context (the conditions during which it takes place). In particular, they assume that it is sufficient to know learner thought processes in order to teach effectively. Yet it is now accepted that all knowledge is contextualised (Perret-Clermont 1992). How can we then apply general processes to spAecific learning episodes? It is at this level that we observe the most glaring failures. To date, all findings emphasize that it is difficult to mobilize school knowledge in professional environments or to transfer daily common sense to school situations. Many obstacles exist, specific to each content and context. Yet most psychologists, including Piaget, do not comment on the learner's activities, on the school or institution, on situations or on facilitating interventions by teachers (this is recognized by Piaget's followers: 'psychology of the student is lacking' Vinh Bang 1989). The same attitude is apparent in Ausubel's, Kelly's or Wallon's publications, even though Wallon is very aware of social factors. Thus a consensus has been emerging to demand that research on learning be more specific, even though studies end up at the crossroads between (1) social and institutional factors (schools, cultural centres and professional areas are first and foremost institutions), (2) psychology (focusing on the mental structures mobilized by learners when learning and not on general mental abilities), and (3) epistemology (the structure and elaboration of knowledge).

In fact, even though we are far from having a definitive model, it is clear that those three kinds of parameters all interact whenever learning takes place. Such interactions and their integration are precisely what is original and specific about education. Yet all three aspects are rarely considered in the research described above. Also, when studying learning, we cannot just focus on learners and their conceptual mechanisms. Although these have an aspect of self-organization, they are largely inter-dependant and related to conditions, and to the successive environments through which they have emerged during each individual's history. It is to fill this gap that we have tried to develop a new model, which combines 'interaction' and 'elaboration' but also 'integration' and 'interference': the Allosteric Learning Model.

### 2.2. Specific criticism

While it is not possible to discuss the numerous above-mentioned theories with regard to comprehension, to the use of knowledge or to memorization, it is nonetheless relevant to present a few comments on how we understand learner thought processes.
It is clear that the comprehension of scientific knowledge is not the simple deciphering of those verbal elements which express a thought (i.e. linguistic or semantic deciphering), as proposed by Vygotsky (1934); nor is it the acquisition of isolated data, as claimed by Gagné (1965). Beyond the comprehension of each element, learning must also relate to whole ideas in response to specific questioning. Likewise, memorization is not a fact-storing mechanism (academic theories), it is also a structuring function. Individuals do not simply register knowledge or skills, these are 'constructed' or 'elaborated'. In fact, this can already be highlighted for simple visual and auditory perception. These are not disconnected from memory (or from higher thought functions), which is needed to provide a blueprint for deciphering.

It is true that genetic or cognitive theories have been more aware of the treatment of information and of the effects of the environment on learning. But the results of those studies are not yet very convincing, for a whole series of reasons.
First, we observe that conceptual learning does not entirely depend on cognitive structures. Individuals that have reached a very high level of abstraction in given areas reason like young children when confronted with new contents. When learning a specific concept, we must not only consider generic reasoning abilities but we must also look at the conceptual structure in each learner's mind. Student thought schemes are not operational in a straightforward way; mobilized conceptions involve multiple interactions, questions, operations, semantic frameworks, reference frameworks, and signifiers, which proAvide an interpretation grid. Further, learners must necessarily connect all these parameters (questions, operations, semantic frameworks, reference frameworks and signifiers) to construct new knowledge. Finally, knowledge will only be mobilized if it acquires meaning for the learner. The issue of meaning is still very rarely considered in genetic or cognitive psychology.

Second, concept elaboration cannot be reduced to learning isolated data. All learning is characterized by multiple connections, by plural organizations. Elementary processes cannot account for all these aspects. Necessary 'abstraction' does not simply 'reflect' but it also deforms, mutates. New elements are not directly integrated into prior knowledge; in fact, prior conceptions are often obstacles to such integration. Data that should promote learning cannot be directly assimilated if it contradicts existing thought structures, and is therefore often ignored. We must consider a kind of 'intellectual deformation' during which new data and existing mental structures interact, and then transform the mental structure. This ultimately leads to a radical mutation of the learner's conceptual network, and not simple accommodation. When new information is integrated into learner thought systems, the latter become richer, but especially transform themself and transform the problem.

The issue of integrating different data within a conceptual framework has not been solved; in fact, the above-mentioned theories are not interested in the structuring of specific knowledge by individual learners. Inter-relations between concepts that produce a specific meaning are rarely considered. Yet, in most cases, concepts which are to be learned are not immediately understood by learners. Students need additional information, coming from other relational systems, and they need to appreciate the meaning and importance of new knowledge. Such essential activities can only take place after learners have realized that they have not Aunderstood relevant information or after they grasp that their thought system is inadequate for solving a particular problem. Generally, we can only understand whole systems after taking their pieces apart to use or to explain them; this highlights the importance of metacognition so that knowledge becomes operational and potentially mobilized.

Finally, if we assume that mental activities are just information processing activities (genetic theories) or even hierarchical information processing (cognitive theories) that can integrate new data into the conceptual systems of learners, we still lack an understanding about the conditions that facilitate learning. Understanding cognitive mechanisms is necessary, but it remains insufficient in order to infer the context or nature of appropriate pedagogic strategies in school or in the media. Yet such strategies are precisely what teachers need to know most. Likewise, psychological theories remain inadequate. This is normal, because teaching strategies are not their primary focus; they have other objectives.

**3. A new learning model**

In order to overcome these shortcomings we have found it useful to promote a new model, which is unique in the sense that its main objective is didactic. The model tries to solve problems that are specifically linked to learning and it has not been transposed from a broader perspective like most of the above-mentioned theories, even though it does contain some borrowed elements. Finally, it allows us to make predictions and proposes a set of conditions that should lead to learning. It is this ultimate aspect, the didactic environment, which is most frequently solicited (Giordan and Girault 1992).
In this paper, we only partially describe our model. For more details, we recommend other publications (Giordan 1987, Giordan 1989).

**3.1. How the model works**

Knowledge appropriation relies on the learner, who is the principal 'mAanager' of his or her own learning. Appropriation takes place both as an extension of prior learning and in opposition to it. In order to understand a new idea, students do not start from scratch, they have unique tools: their conceptions. These provide a questioning framework, a way of reasoning and necessary references. It is through this analysis grid that learners interpret the situations they encounter and decipher the various data that grasp their attention.

However, significant learning can only occur when learners break away from their initial conceptions. When they acquire a new concept, their entire mental structure is deeply transformed, their questioning framework is completely rephrased, and their reference grid largely re-elaborated. This is what has led us to propose that students learn 'thanks to' (Gagné), 'from' (Ausubel), and 'with' (Piaget) the functional knowledge in their head; yet, simultaneously, learners understand 'against' (Bachelard) such knowledge.
In fact, to learn, students must often work against their initial conceptions but this can only happen by working 'with' them until they 'crack', i.e. appear more limited or less fruitful than alternative conceptions that have been formulated.

It is essential that learners have the opportunity to implement such an approach. This is not the result of chance, and can only take place within existing structures (questions, reference frameworks, mastered operations) and because of the importance learners give to a question.

Thus, conceptions are not only the starting point, nor simply the result of mental activity. They are the instruments of mental activity. To embrace new knowledge learners must integrate it into functioning conceptual structures. New conceptions replace old ones by modifying prior conceptual structures. However, the main thing that changes in a learner's mind - and this is clearly shown by the allosteric model - is not the data themselves but the network which coAnnects them and produces meaningful answers.

Consequently, each learner is at the heart of his or her knowledge construction. Knowledge is not transmitted; instead, it results from an elaboration activity during which conceptual systems are mobilized by learners who confront new information with mobilized conceptions and produce new meanings, which are more adequate for answering the questions asked. Teaching the concept of 'circulation' in primary school or early secondary school is not obvious. To disseminate the idea that blood circulates does not have any 'meaning', since the definition of 'circulates' is generally unclear. One way or another, we observe that the message does not get across without referring to underlying questions.

1. One possible motivational approach towards this concept might be nutrition. Organs or cells (depending on the learners' age) need food. How can they obtain it? Students easily see that organs lack direct access to the outside world. Which method did animals develop to solve that problem? At this stage, blood, which is already known, is given the role of 'transport liquid'. Such a conceptual disequilibrium will grasp the students' attention. However, all obstacles are far from being overcome. We still need to convince learners that nutrition is something that each cell or organ needs, not just the body in general ('we need to eat in order to live'). Time to discuss such issues must be provided.

2. Cellular excretion can mobilize this first message and reinforce the role of blood. However, the idea of bringing food and removing waste products does not necessarily imply circulation (in the sense of circle). Historically, 'watering hose' mechanisms were considered. This difficulty can be overcome by confronting students with another question: Is blood constantly added like water in a hose? If not, does it remain unchanged?

A simple calculation may help:
- about five litres of blood go through the heartA each minute;
- we cannot produce that amount of blood each minute, especially since the total volume of blood in our body is about five litres.

This argument challenges the watering hose model but it is not sufficient to trigger the idea of circular transportation. For this, it is useful to introduce circuit models. Transportation alone might make learners thing of road traffic, where cars can go back and forth on the same road. Teachers must trigger the idea of circuit, directly or indirectly, through the situations they provide. Common models are often inadequate because respiration and nutrition are superimposed and confusing. Possible confrontations might include:

- A movie, which shows a transparent fish embryo in which the simple circulation of red blood cells is visible;
- The study of veins and arteries, and of what happens within organs (work on capillary vessels);

- The construction of dynamic models to visualize the path of blood, including a pump, organs and various kinds of tubes which materialize the circulation system's functions. In exhibits, the possibility of visualizing moving balls using changing lights or colours (due to temperature) can help understand the transformation of blood within organs and in the lungs. In classrooms, such models may be constructed using recycled materials. I have suggested a practical approach to model building, but students may also successfully construct paper and pencil models.

3. The idea of nutrition can be mobilized for discussing respiration, which is another topic that can easily interest students. 'Oxygen must be brought to cells' (or organs). In this case, however, there is a very large obstacle to overcome, i.e. the fact that respiration takes place outside the lungs. Finally, multiple links can be made by students:

- Food + oxygen = energy.
- Organs need energy.
- Organs produce their own energy (like vehicles).

Each aspect of this topic requires explanaAtions as well as student-student or student-document confrontations. Conceptograms may help learners achieve this. Another related obstacle to solve is: how can we discuss oxygen without promoting the frequent misconception that it is some kind of vitamin. Once all these elements are united, we can further reinforce this knowledge by mobilizing it in new situations.

**3.2. Obstacles to learning**

Because of its explanatory power the allosteric model allows us to predict a series of obstacles to learning. These may occur at different levels and require a variety of specific solutions. In some cases, necessary information may be missing. In others, the required information is available, but the learner is not motivated by the question or preoccupied by something else. In a third set of cases, learners may not be able to access necessary information because they lack appropriate methodologies, operations or references. Finally, in most cases, learners lack the elements that enable them to effectively manage their learning.
These last two situations are the ones for which the allosteric learning model is most relevant. For fundamental learning, the model shows that the knowledge to be acquired is never automatically built upon prior knowledge; most often, prior knowledge is an obstacle to the integration of new knowledge. Thus, we must consider a radical transformation of the learner's conceptual framework and this implies a series of conditions.

- First, the learner must be able to see beyond familiar knowledge. This is not easy, because the existing, activated conceptions are the only tools which are available to decipher reality. We must therefore continually challenge conceptions since they inevitably lead to the same answers and are a 'filter' upon reality.
- Second, the initial conception is only transformed if a learner is confronted with a whole series of converging and redundant elements, which end up beiAng quite difficult to coordinate.

- Third, learners can only elaborate new conceptual frameworks by linking stored information in a different way, for example on the basis of organizing models which allow alternative knowledge structures.

- Fourth, concepts that are being elaborated require gradual differentiation to become operational; at first, their scope must be limited while learning; then, new knowledge can be strengthened through mobilization in other applied contexts.

- Finally, learners must deliberately control their learning activity and the processes, which regulate this activity, in several ways. First, learners must reorganize the information which is presented to them (or which is obtained) depending on how they appreciate specific situations, elaborate meanings or represent knowledge. Then, the learner must reconcile all these parameters in order to construct new knowledge - so that it can be used again. Finally, the learner must pinpoint similarities and differences between old knowledge and new and, quite frequently, solve apparent contradictions.

**3.3. Conditions for knowledge transformation**

If any one of the above-mentioned conditions is not fulfilled, learning may be compromised. Learner thought processes are not passive recording structures, which engrave new knowledge on virgin soil. Each learner's mind has its own explanation modes, which shape the way new information is perceived.
Conceptual frameworks, which are unconsciously constructed on the basis of individual experiences and interpretations during prior learning situations, are a genuine filter for each new acquisition.

Therefore, learners themselves, for some reason or other, must decide to change their conceptions. If teachers do not take this into account, student conceptions will resist changes and remodelling. But learners do not simply run assimilation-accommodation procedures. Self-regulating proceAsses do occur, but they cannot be viewed as 'cognitive bridges' (Ausubel) or 'reflecting abstractions' (Piaget 1976).
The best word to describe learning mechanisms is 'elaboration'. Learning takes place in a conflicting and in an integrating mode. In addition, it interferes. Such interferences emerge from the multiple interactions which must take place between conceptions and the context of learning or between the numerous elements of each conception (questioning framework, references, conceptual process, various markers). The production of meaning is at the heart of each learner's knowledge construction process. By sorting, analysing and organizing data, each learner elaborates a personal response to a given question. Nobody can do so in his or her place. This implies that the learner must feel challenged by a particular question. Only learners can strive to integrate newly acquired information in order to produce meanings that are compatible with the prior organization of their mental structure. This is why the notion of interference is important, requires time, and necessarily goes through several stages.

The motor of this process is not simple 'maturation', however. Rather, the emergence of new conceptions depends on the internal conditions that regulate a learner's thoughts, as well as on the external conditions in which the learner is immersed, which also interfere to a large extent. In fact, the mental network which is mobilized, and which links the learner's conceptual framework with information gathered within school and outside it, is what's relevant, not the sequence of recorded

data.
Yet while we recognize that learning is not a cumulative mechanism, this is the notion which underlies all curricula: knowledge is divided into topics, chapters, sections, etc. which are tackled in sequence, with the hope that their juxtaposition will somehow reconstitute the whole knowledge system.

Knowledge appropriation must be considered a sequence of operations Athat provoke gradual and systemic mental transformation, whereby it is essential for each learner to feel concerned, and challenged. Unfortunately, in many cases, 'cold' knowledge is proposed to students, i.e. without their prior questioning.

**3.4. A didactic environment**

Such processes do not occur by chance. They must be facilitated by what we call a didactic environment provided to students by teachers, or, more generally, by cultural and educational contexts. In a limited time span, it is very unlikely that learners 'discover' on their own all the elements, which enable question transformation, inter-relations, and reformulations. Even self-taught learners recognize that their acquisitions have been facilitated by circumstances. The allosteric learning model can identify significant parameters of this environment.

First, the educational environment must induce a series of relevant conceptual disequilibria. The learner must develop the desire to learn, and to construct. Thus, the learner must be motivated about the question or issue at hand; at the very least, learners have to try to participate in a new way of thinking.
It is essential to ensure a certain number of authentic confrontations. These may be student-reality confrontations via surveys, observations or experiments, for example. Or else, they can be student-student confrontations during group projects, or confrontations with sources of information. All these activities must convince learners that their conceptions are not sufficiently adequate for the problem they are addressing. The activities should help students express their thoughts and help take a step back from ideas that they hold for granted; this is mainly achieved through problem reformulations and/or the considerations of new links. Also, activities may lead learners to collect new data that enrich their experience.

Second, it is important for learners to have access to an appropriate leveAl of formalism. Such formalism, which may have various guises (symbolism, model-building, schematisation), should help us think. Consider, for example, Arabic numerals: these facilitate the acquisition of multiplication rules compared with roman numerals or with the Middle Aged abacus. Obviously, the chosen symbolism must be easily accessed and manipulated by learners. It must correspond with their vision of reality, allow the organization of various data and be an anchor for new knowledge structures. In particular, the introduction of models always enables new visions of reality. Models should be a 'hard coreí, which federates information and produces new knowledge.

It is not easy to trigger knowledge elaboration activities within each learner for a given topic. For instance, when studying photosynthesis, some students may think they 'know' that 'plants get their food from the ground' and thus have little motivation to know more about the topic. Various examples can successfully challenge these conceptions: plants that grow above ground, hydroculture, mistletoe, water lentils, etc. It is important that the student's approach and attitude reaches a certain level either before addressing new knowledge, or in parallel with learning activities. This facilitates their questioning and helps them distance themselves from observed phenomena. Genuine confrontations are always essential requirements (e.g. student-reality or student-student confrontations), as they enable learners to explain their own thoughts to a group. Further, various exercises should help students acquire new data and enrich their direct knowledge of each topic. New findings from observation and experiment (varying light, temperature, CO2 concentration, minerals, etc.) can test each student's conceptions. This should enable students to challenge their assumptions and frequently reformulate the problem (what does nutrition mean?) and or consider other links (e.g. food-energy connection). It is essential that tAhe arguments come from varied sources; teachers should never rely on a single, rapidly presented argument. Finally, all these elements must be appropriate with regard to the student's reference framework, or else they will be ignored.

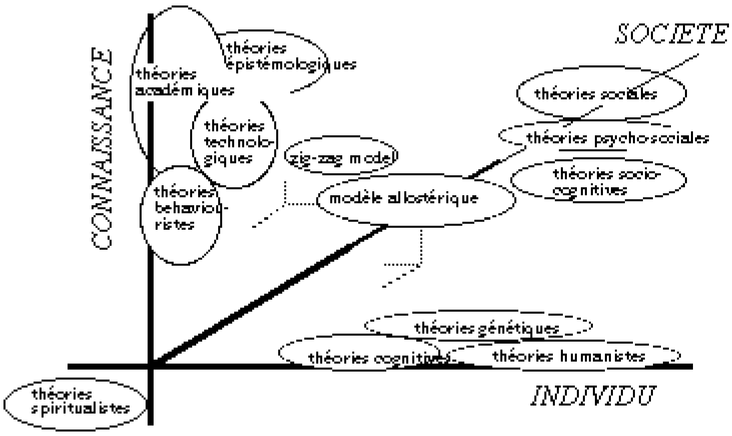
For students who already know how to use the scientific method, learning is facilitated by student-information confrontations within the framework of a making a documentary, for example (about plant cultivation on various soils, interactions between several factors, the role of fertilizers, humus, and manure, etc.). All these activities should convince learners that their prior conceptions are inadequate or incomplete with regard to the problem they need to solve, and that other models appear to be more operational.
Also, learners must have access to a certain degree of formalism, which helps them think. Such formalism may be quite diverse (schemes, models). It should be easy to manipulate, help organize new data and help produce new knowledge structures (anchors). The introduction of a global model can be the 'hard core' around which information can gradually federate as it is encountered.
Specific models may often have compartments. Certain partial models in each compartment may have to be considered to specify each issue (the role of light, chloroplasts, respiration versus photosynthesis, energy transduction). In each case, these must be adapted to the student's conceptual framework. Finally, we must add that for the concept of photosynthesis to be really operational, learners must be provided with situations in which they can mobilize their new knowledge, test its operationality and its limitations (e.g. plant cultivation activities, food chains, etc.). At a didactic level, several investigations are taking place. Various methods appear to be useful depending on the circumstances.
Research has shown that it is good if teachers initially provide the rough outline of a model, but they must remain very cautious. Such 'pre-models'A must be easy to understand and adapted to the way each learner views the problem. It is desirable that learners should have had the opportunity to become familiar with such models beforehand; for example, by producing one themselves or maybe by seeing how it works...
It is especially important for the learner to have become aware of the fact that there are no 'good models'. Each model is only a temporary approximation of reality. So, it is useful for students to 'juggle' with several models, testing each model's operationality and limitations.

Third, it is useful to provide learners with situations in which they can mobilize their knowledge after it has been elaborated. These activities are essential in order to show students that new data are more easily learned once they have been integrated into receptive structures and put to use. Isn't it true that we learn best when we have to teach a given contents or put new knowledge into practice? Likewise, these situations familiarize learners with the 'grafting' of new knowledge upon old.

Learners can therefore get used to shuttling back and forth between what is known and what is being learned. Prior attachments are then easier to overcome.

Finally, it is desirable for learners to understand our 'knowledge about knowledge'. Several of the difficulties we have observed are not obstacles linked to the contents of knowledge, but instead are indirect problems, which result from the learner's conception of learning and his intuitive epistemology of knowledge production mechanisms. In other words, learners should be encouraged to think about their conceptual practices from a young age onwards. What is their scope, their focus? Which approaches take place in a classroom? What is their underlying 'logic'? Why shouldn't knowledge and learning become an item of study... in schools!

**4. Conclusion**




In conclusion, it is possible to illustrate the various theories on a graph whose three axes are dAefined in section 1. Most current theories remain very close to a single axis, i.e. they emphasize a single parameter.

The allosteric learning model, on the other hand, and also, to a lesser degree, Schaefer's 'zig-zag model' (which is described in the same publication) are novel. They are multifactorial, and integrate several parameters. They are especially relevant because they are situated at the convergence point of several elements and produce a relational system. In the allosteric model, as explained above, learning is not dependant on a single factor, but on a network of conditions we call the 'didactic environment'; this overwhelmingly important for teaching, and for science popularisation in general. In fact, it is the history of these conditions that happens to be crucial.