MOTOR LEARNING AND TEACHING.
A SYSTEM-THEORETICAL APPROACH

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We were born without expertise,
And will die without experience.
Wisława Szymborska

Introduction

One of the greatest "inventions" of evolution was no doubt the feedback control mode. It enables learning and – indirectly – species' development. However, it is rather "expensive" in terms of intellectual work. So, in learning process the feedback is necessary, indeed, but in the performance of already mastered skill its part should be reduced to minimum or eliminated at all. The comparison of the terms "performance" and "learning" is shown in tab. 1.

Table 1. Comparison of the terms "Performance" and "Learning" [Magill, 2011, p. 249].

Performance	Learning
• Observable behavior	• Inferred from performance
• Temporary	• Relatively permanent
• May not be due to practice	• Due to practice
• May be influenced by performance variables	• Not influenced by performance variables

The process of learning includes the changeability of movements' management structures along with increasing experience. It may be defined as follows:

Learning *– «the psychological, intrapersonal process of transformation of respective mental representations of specific tasks, aimed at enhancing future solution of similar task».*

N.R. Carlson distinguishes two kinds of learning:

Perceptual learning *– «learning to recognize a particular stimulus».*

Motor learning – *«learning to make a new response»* [Carlson, 2007, p. 431].

The very basis of learning and teaching processes (as well as motor control) make the information processing and development of relatively stable and efficacious patterns of motor behavior being the solutions of specific environmental tasks. They need using of suitable codes and methods of information processing (in living beings termed "thinking"). However, unlike in technological devices, in living beings the information processing is of multimodal nature.

Multimodality of information processing in living creatures. The modalities ladder

Unlike the physical processes, the biological ones are hardly liable to mathematical mirroring and description [Buytendijk, 1956; Brillouin, 2004; Kawato, 2008; Heller, 2011]. To bring this region of scientific knowledge into order, the systemic approach seems to be suitable.

The most primeval roots of systemic thinking one may trace already in antiquity. In 17th century the ideas by R. Descartes (division into *res cogitans* and *res extensa*) may be regarded as a germ of a system idea, though according to Cartesius it was a sum rather, and not a system. In 1852 British biologist W.B. Carpenter has presented a systemic arrangement of information processing in humans [Carpenter, 1852], and in 1884 British physician J. Hughlings Jackson developed a three-level neurophysiological model of information processing in humans [Hughlings Jackson, 1884]. In 1947 Russian neurophysiologist N.A. Bernstein (who referred to Hughlings Jackson, but not to Carpenter) invented probably the most advanced model of movements production in humans. It consists of five levels: A (rubro-spinal), B (thalamo-pallidal), C (pyramidal-striatal), D (cortical) and E (cortical) [Bernstein, 1947].

Independently, in sixties of 20th century, American neuroscientist P.D. MacLean (who referred to Hughlings Jackson, but not to Bernstein) has presented three-level model termed "triune brain" [MacLean, 1985; MacLean, 1990].

Neurophysiology is important, indeed, but in motor control most significant is the way of motor behavior patterns production. Thus, on the basis of Bernstein's theory it seems possible to develop what might be termed the "modalities ladder" (ML). The simplified presentation of it is shown in table 2.

Table 2. The modalities ladder.

Bernstein's level	**Stimulus**	**Type of skill**	**Type of control**	**Type of internal pattern**
E	Engram –symbol	-	Politics	Vision
D	Engram – word	Performance	Strategy	Program
C	Remote (mainly visual)	Habit	Tactics	Image
B	Contact	Automatism	Technique	Stereotype
A	Intrinsic	Reflex	Internal	Coupling

It is worth noticing that in table 2 there is neither a "conditioned reflex", nor an "unconditioned reflex". Those historically established names are rather confusing, because they suggest that one has to do with two varieties of the same phenomenon. On the contrary, each of them is controlled by another neural structure, each has its specific attributes and both they play different roles in the general structure of human (and animals') movements.

Engram is a memory trace, i.e. internal representation of either environmental phenomena or processes, or product of internal processing of such representations. In short, one may state that A-level is a "feeling-in-hand" level, B-level – movements' harmony level, C-level – "measure-by-eye" level, D-level – "common reason" level, and E-level – fantasy level.

Very important is that the lower level, the less complex an less "powerful", but at the same time less time-consuming information processing. So, on automatism may include several reflexes, one habit may "command" several automatisms and one performance – several habits. The opposite direction is not possible.

The phases of motor learning according to FITTS

In 1964 P. FITTS developed a three-stage model of motor learning [Schmidt, Lee, 2011]. He divided the whole process of motor operation learning into three distinct phases, which make a single, coherent and continuous developing system of the internal representation of motor operations. It consists of:

1. The cognitive phase,
2. The associative phase,
3. The autonomous phase.

So, the learning process depends on efficiency of feedback control, but it is aimed at elimination – as much as possible – of this control mode and substituting it with the feedforward control, most desired in movements' control processes.

Cognitive phase: Down the codes' ladder

In cognitive phase the learning individual applies at first the most powerful information processing tool, i.e. E-level **fantasy** [Petryński, 2010a]. Here: the "independent variable" is a planned action, and the "dependent variable" – the environmental conditions. At D-level (common reason) situation changes: the environmental conditions play the function of "independent value", and the action has to be adjusted to them. At C-level ("measure-by-eye") the visual image of a planned action is being produced, at B-level (movements' harmony) – the muscle synergies, and at A-level ("feeling-in-hand") – the particular muscle contractions (fig. 1).

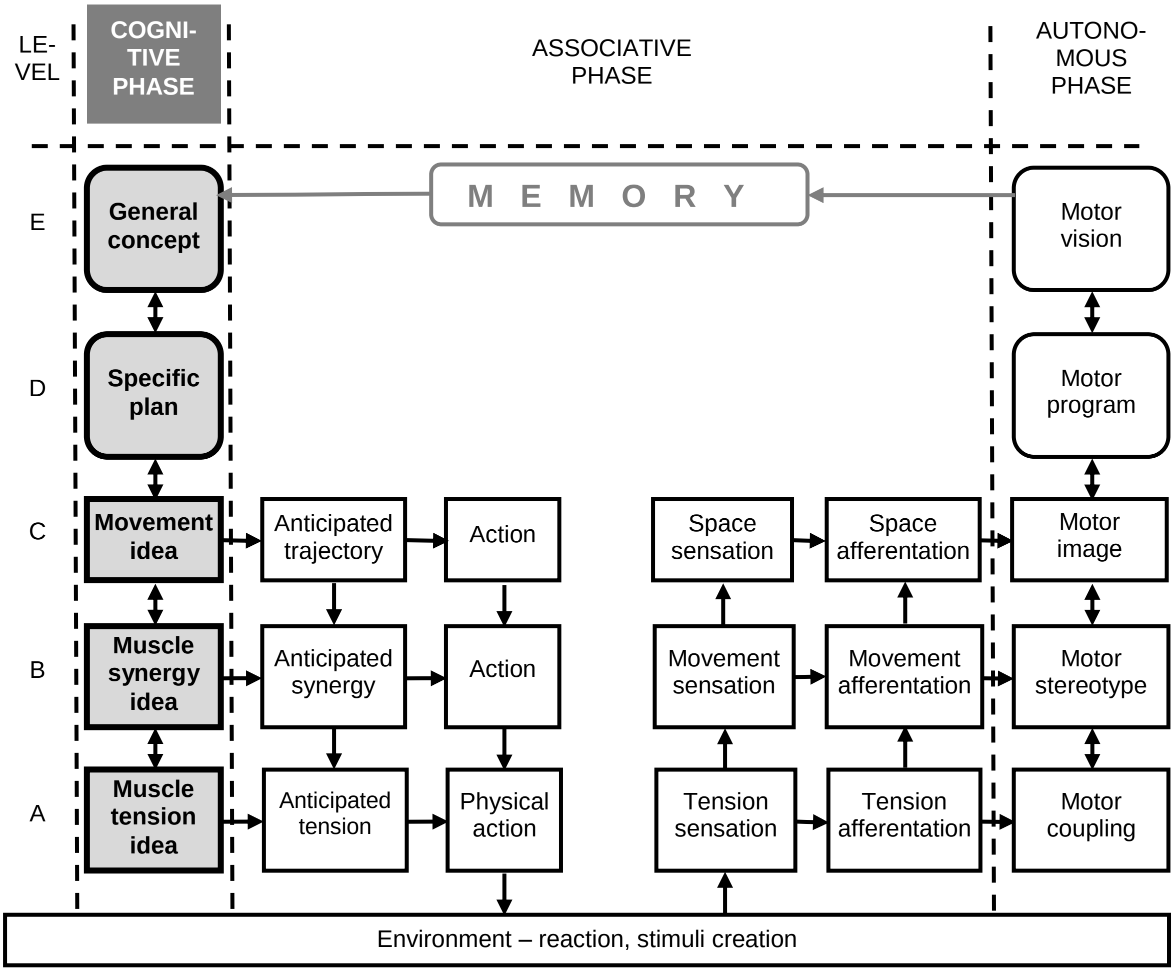

Figure 1. Motor learning, **cognitive phase**: going down the modalities' ladder.

While looking from physical perspective, the A, B, C, D and E levels are "responsible" for dynamics, kinetics, kinematics, metric and topology of the movement, respectively, to be emphasized that in cognitive phase we have to do with **abstract conceptual representations of sensory phenomena**. So, abstraction is not assigned exclusively to D and E levels, "structurally" deprived of physical contact with environment.

Associative phase: Bridging the gaps

After the rough ideas of particular actions at different levels of CL are already prepared, the system gets ready to produce motor commands' structures corresponding to them. So, it is necessary to bridge the gap between imagination and the results of real actions, i.e. to check in practice the tentative working hypotheses developed in cognitive phase. This gap is clearly visible in fig. 2.

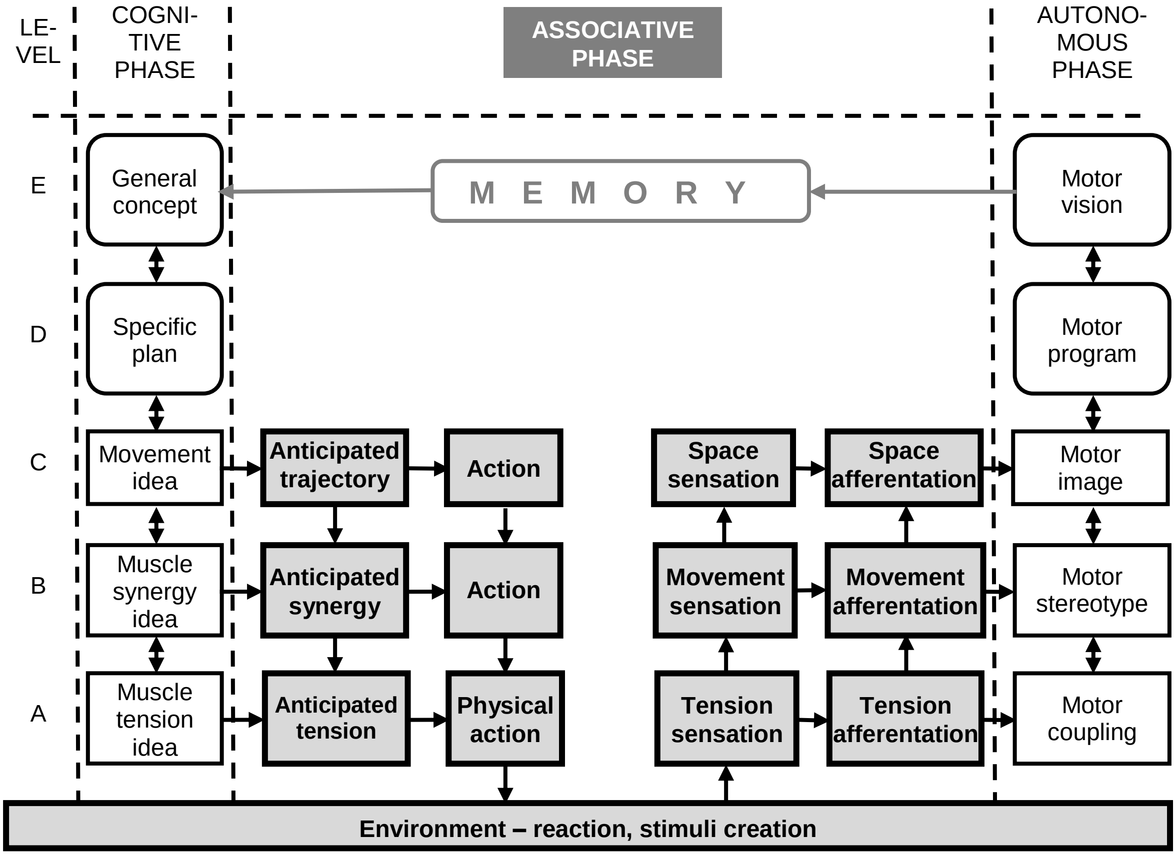

Figure 2. Motor learning, **associative phase**. Bridging the gap, clearly visible "gap" between action and sensation.

It is placed between columns "Actions" and "Sensations", and the only way to bridge this gap leads through the reaction of the environment.

The next step is the production of abstract afferentations on the base of physical sensations. Just the afferentations make the “building stuff” for purely abstract motor behavior patterns at particular levels of ML.

Autonomous phase: Up the modalities’ ladder

Creation of abstract motor behavior patterns makes the essence of the third element of Fitts’ theory, i.e. the autonomous phase (fig. 3).

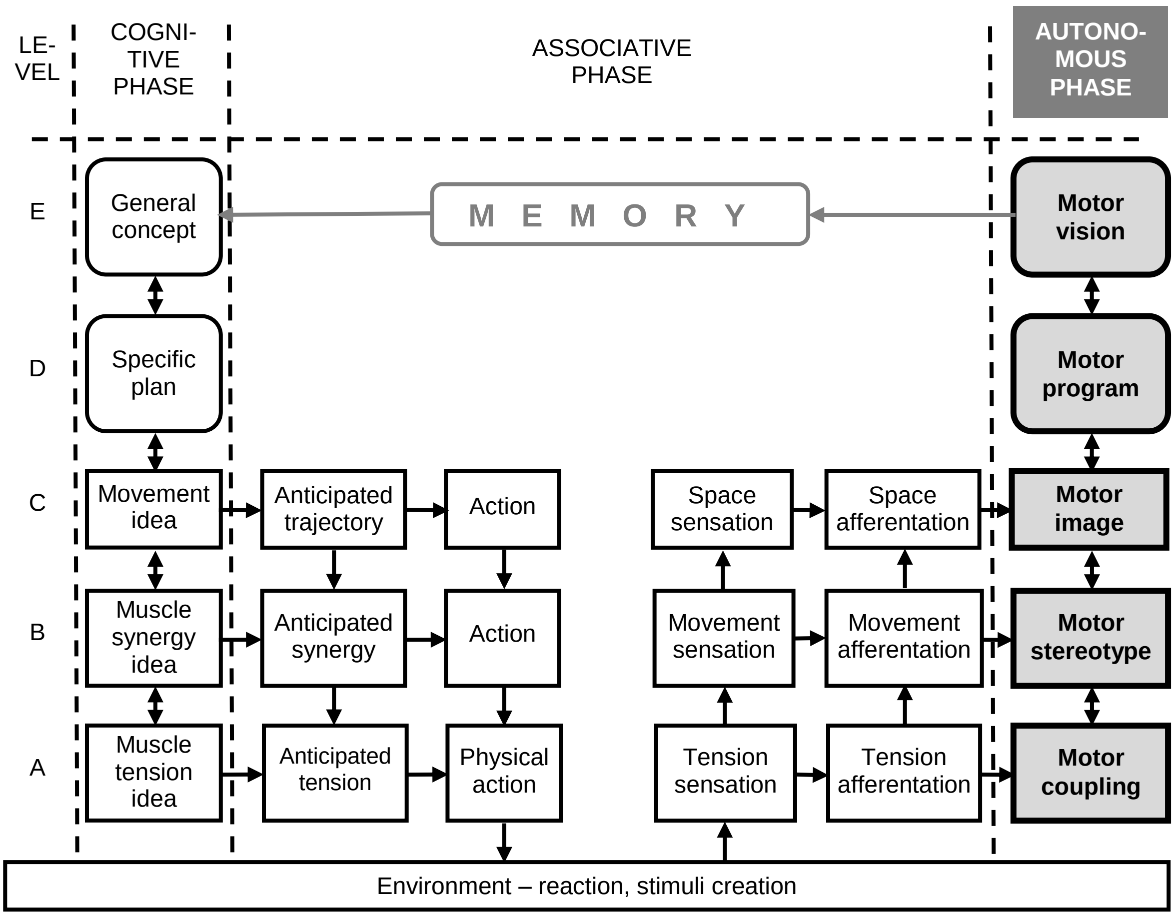

Figure 3. Motor learning **autonomous phase**; going up the modalities’ ladder.

The **abstract** afferentations may be transformed into **abstract** behavior patterns. They have two major advantages over ideas developed in the cognitive stage:

1. They are free from environmental noise that has to be eliminated before an action starts.
2. They are independent of environmental stimuli, so it may be initiated on the base of anticipation, before an essential stimulus appears.

In the point 2 appears the very important word “**anticipation**”. It may be effectively applied when:

1. The environment is predictable enough.
2. The active person has properly recognized the task.
3. The active person has previously developed appropriate motor behavior patterns.

In such a situation the feedforward mode is sufficiently efficacious and there is no need to carry out the time consuming feedback processing. So, in movement control the feedback may be regarded as a rescue action, some sort of prosthesis, necessary to save otherwise lost motor operation [Petryński W., 2010b]. This is why in figs. 1, 2 and 3 the block “Memory” is marked with grey lines, because the learning process is aimed at elimination of its role when the internal behavior patterns achieve their optimal efficiency.

External support for the motor learning process: Teaching

In figs. 1, 2 and 3 the **psychological process of learning** is shown, i.e. the confrontation of primary imagination with real environment’s reaction and transformation of sensations into afferentations that in turn make the “building stuff” of abstract, internal motor behavior patterns.

Though the learning is decisive in the process of improving the human motor competencies, in the course of evolution – from herd, through tribal to social modes of cooperation – the process of teaching that supports individual’s learning has been developed. It enables extending the particular skills perfecting to the intergenerational temporal scale. Accordingly, it may be defined as follows:

Teaching – *«the sociological (interpersonal) process of effective supporting the intrapersonal learning process in an individual».*

In short, teaching consists in substituting the environmental response to individual’s action, i.e. feedback, with cues delivered by a teacher. Such feedback is aimed at:

1. Breaking the process of creation of a wrong motor behavior pattern.
2. Inducing the learner to create a right pattern.

The general pattern of the teaching process, while seen from the ML perspective, is shown in fig. 4.

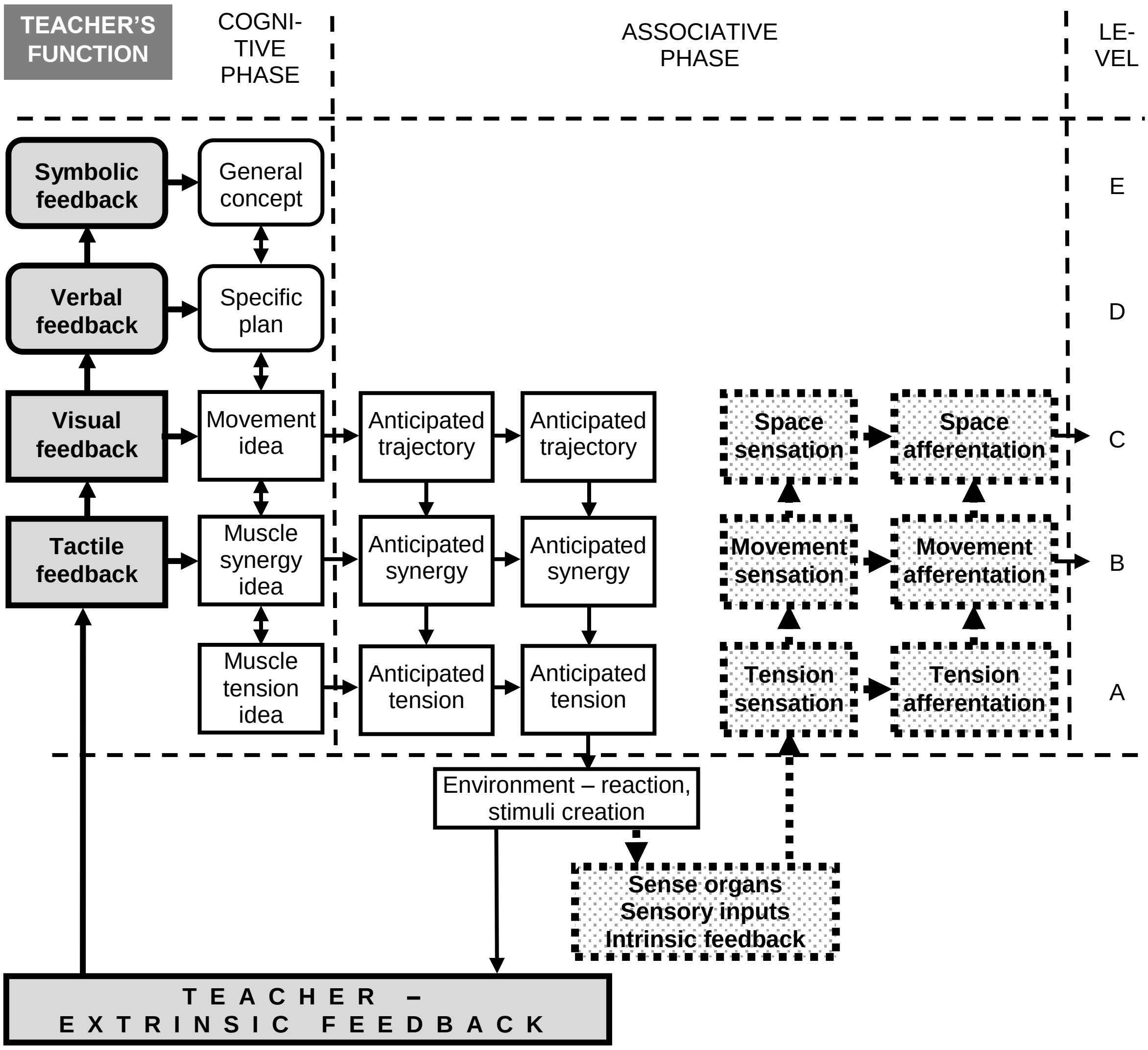

Figure 4. Teaching as seen from the modalities' ladder perspective.

While noticing an incorrect or inefficient performing of an action just being learned, a teacher (instructor, coach) should break the process of "bridging the gaps" in the association phase and substitute the environmental reactions with the proper cues, described in fig. 4 as "Teacher – extrinsic feedback". In short, teacher has to suppress the environmental feedback and substitute it with one's own instruction.

The teacher has no access to the A-level intrinsic sensations, i.e. creation of "feeling-in-hand". For example, it is not possible to explain, how strong one has to grip an egg to prevent it both from falling down and from crushing its shell. Such "feeling-in-hand" – and respective coupling – has to be shaped independently by learner.

Only at B-level (movements' harmony) teacher may actively influence the way of performing the learner's action. This is termed guidance [Schmidt, Lee, 2011, p. 386-388; Park, Kim, Obinata, 2011], or more precisely – tactile guidance. This technique is sometimes applied in rehabilitation of a person with injured nervous system. In sport or physical education it application is theoretically possible, indeed, but it induces a learner to sheer **reproduction** of specific movements (stereotypes). As a result, its "learning power" is rather poor.

At C-level ("measure-by-eye") teacher may apply a visual feedback, i.e. demonstration. It gives ready image of a given action, so it induces the learner to **imitation** of teacher's action.

At D-level (common reason) the teacher delivers verbal description of an action to be done by learner. It gives ready program and the learner should realize it, i.e. to produce or reproduce independently necessary images, stereotypes and couplings. Such verbal description is commonly known as "knowledge of performance", in short KP. The learner is induced to **realize** the rather strictly described motor program.

At E-level (fantasy) the teacher delivers only an assessment – "good" or "bad" – and the learner has to **create** independently a proper program and respective system of images, stereotypes and couplings. This kind of teacher's cue is termed "knowledge of results", in short KR [Knapp, 1963, p. 323; Belej, 2001, p. 56; Schmidt, Wrisberg, 2008, p. 286; Schmidt, Lee, 2011, p. 395].

Summing up, in spatial and temporal terms E-level is "responsible" for general topology of movements that make together an efficient motor performance; D-level – for metrics; C-level – for kinematics; B-level – for kinetics; and A-level – for dynamics.

It is worth noticing that there are only two "input gates" from environment to the human system of information processing – at B- and C-levels – and only one "output gate" at A-level. Accordingly, a teacher may analyze the only observable manifestation of internal mental processes in a trainee or learner – i.e. the movement – and only infer, what is wrong and needs corrections in disciple's mind to make the teaching process effective.

As already mentioned, the lower level, the more straightforward information processing, but at the same time – the faster. So, in very quick actions, as hitting or throwing – so called "ballistic movements" – only feedforward control mode is possible. In such motor operations a teacher is able, especially with verbal instruction, to show the already made errors.

Also in moderately quick motor operations the visual control may be applied, but verbal information processing would be to slow. Thus, when in a given situation the visual information processing is not effective enough and the verbal transformation has to be applied, an individual stops his/her actions and says: Just a moment, please, let me ponder over it!

However, in didactical practice the most popular is the verbal presentation, i.e. the lecture. When it is given in the lecture room, sometimes with special audio-visual didactical aids, then the speed of “transmitter” complies with the speed of “receivers”. Moreover, as it is fully detached from real run of events, the formed may be easily adjusted to the latter. In such situation the potentialities of verbal information processing may be exploited in full. It is completely detached from purely sensory experiences, so it may reach far beyond the sensory limitations.

In motor control other popular way of teaching is the demonstration. It exploits the potentialities of remote modality of information processing. It is much quicker than the verbal one, but at the same time much less “powerful”. Visual, auditory, or olfactory modality is tightly connected with sensory experiences, thus its spatial and temporal frames are limited by the potentialities of human’s senses.

The specific method of teaching, especially in sport and physical education, is the instruction. It is a verbal cue given during the just being performed operation. So, here one has to join two incompatible ways of information processing: rather slowly “transformable” verbal directives and rather quickly running motor operation. This is not always possible, but to make it effective in a case when it may be effectively applied, the instruction has to be:

1. Extremely short, understandable and concise.
2. It has to concern the essential elements of what is going here and now.
3. It should evoke in the memory of the disciple a simple image rather, and not – say – a chapter from a 1000 pages book.

Let us remember, once more, that the movement is the only possible manifestation of what is going on in human’s mind. Thus, a teacher has to be able to “read” the motor behavior of trainees effectively enough to give them a useful assistance. Moreover, it has to be done as quickly as it would be processed with sensory modality. So, the instruction is probably the most difficult way of motor operations teaching.

It is also worth noticing that each motor action – reflex, automatism, habit and/or performance – is always directed to the future that is inevitably burdened with some uncertainty. So, each motor action may be planned only with some probability of the final success. It seems that just this probability makes the further progress and evolution of whole species' possible.

The modalities' ladder and the learning cycle by D.A. Kolb

The presented paper includes a tacit premise that the sensory inputs – neural impulses induced by extrinsic stimuli, tactile (B-level) or remote (C-level) – only recall respective information chunks from memory. In other words, information comes not from outside, but – according to cognitivist idea by J.S. Bruner – is being created, processed, and stored inside the system [Bruner, 1973]. Whole transformation and processing of the information chunks happen inside the specific mind of an individual. Such transformation is strongly influenced by one's own experiences and knowledge. So, even the same stimuli evoke different information in different individuals. Such a mental diversity may be regarded as a basis for intellectual development of humans as a species. However, on the other hand, just this makes the job of a teacher, instructor or coach extremely difficult. So, by now it is more art than trade. To put it short and clear, a teacher does not transmit information, but only recalls it from the memory of disciples.

By the way. Taking as a basis the cognitivist idea by J.S. Bruner is no doubt a philosophical premise. As the outstanding mathematician, D. Hilbert has stated „*Philosophy is a game with objectives and no rules. Mathematics is a game with rules and no objectives*. So, philosophy and mathematics make the intellectual "Pillars of Hercules", with the science somewhere between them. Accordingly, in really innovative science there are neither completely clearly defined objectives, nor absolutely sharp rules; it seems that just this probabilistic fuzziness makes a basis for progress and evolution. As a result, it is necessary to choose arbitrarily a starting point for further analyses. Thus, taking as such a starting point e.g. the Bernstein's or Bruner's ideas seems to be fully justified.

All the more, the Bruner's cognitivist perspective is not only a purely philosophical basis underlying one of many scientific world images. It has also very practical application and makes one of the fundamentals of neuro-linguistic programming that consists to great extent not in shaping of desirable behavior patterns by teacher, but in “potentialities mining” from one’ own psychological resources by disciple [Andras, Faulkner, 1994].

The presented model of motor learning and teaching is not contradictory to commonly known learning cycle invented by D.A. Kolb (fig. 5) [Chiong, 2011], though the latter does not take into account the full spectrum of modalities involved in the process of learning (and teaching, too).

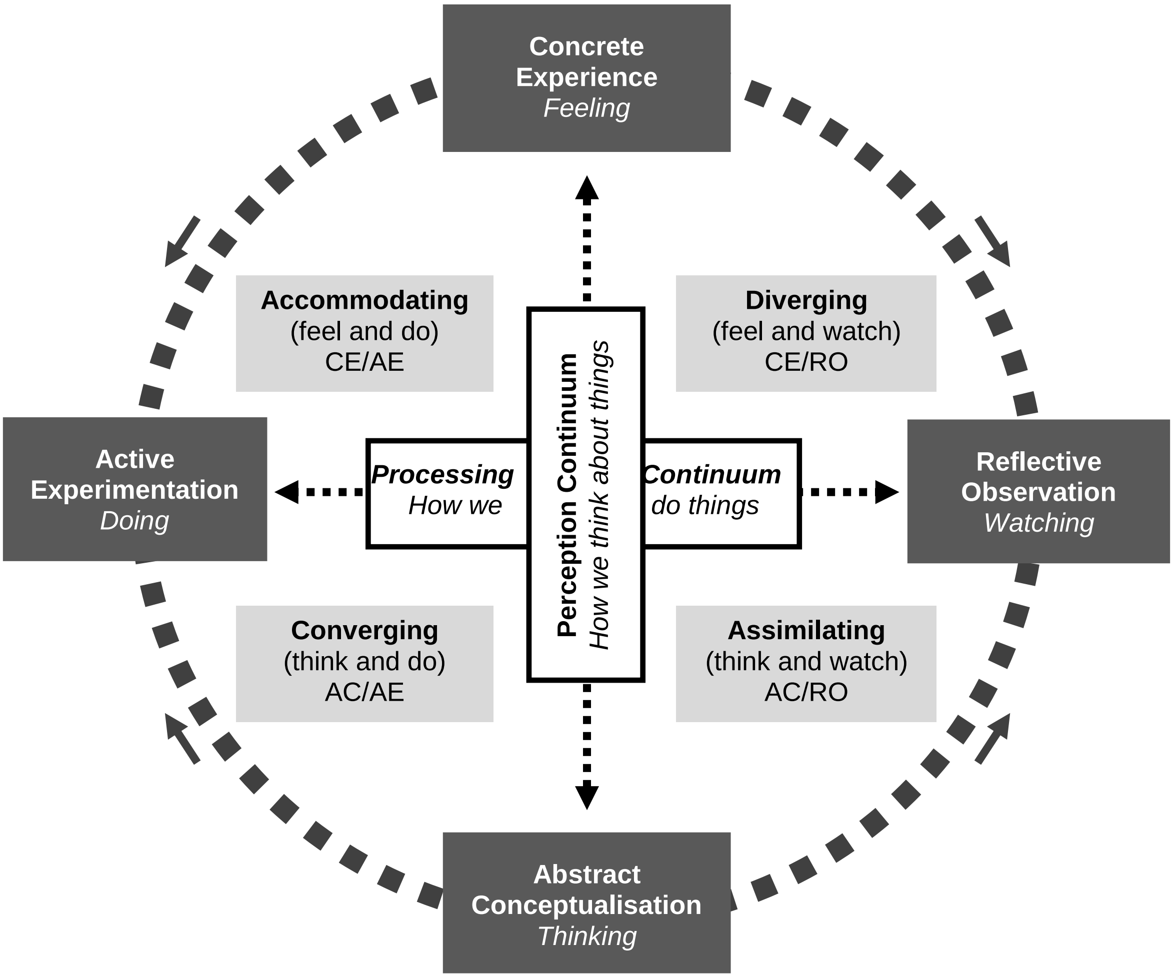

Figure 5. The learning cycle by D.A. Kolb [Chiong, 2011], slightly modified.

On the contrary, the ML model may support that by Kolb. In fig. 5 slightly inconsequent seems to be categorization of “concrete experience” as an element of the block “*How we* ***think*** (our emphasis – authors) *about things”.* “Feelings” are of sensory, and not of mental nature. However, while looking at fig. 2, one may learn that in the association phase a sensory feeling produces abstract, mental afferentation. Both they are strictly assigned to each other. As a result, just the mental afferentations may be categorized as the elements of intellectual, and not purely sensory processes.

It is worth noticing that Kolb discusses the learning styles, not being analyzed in the ML model. So, both the theories may effectively support each other even in this respect. Unfortunately, the possible analysis, however promising, would probably go far beyond the limits of a single paper.

Conclusion

It is worth noticing that the most important events underlying the motor behavior of living creatures, and especially a human, are liable neither to direct experimental verification, nor to simple mathematical description. In physics situation is quite simple: the reactions are unambiguously assigned to specific stimuli (at least in statistical terms) and there is nothing between them. On the other hand, in motor control between a stimulus and response (no longer a sheer reaction!) there is an information that has to be identified and processed.

As already mentioned, the only visible manifestation of all the internal processes is the motion. So, it seems instructive to quote the following words by R. Dawkins:

> *Careful inference can be more reliable than "actual observation", however strongly our intuition protests at admitting it* [Dawkins, 2009, p. 15].

As a consequence, the experimental methodology of scientific research, very effective in e.g. physics or chemistry, cannot be equally fruitful in biology (in a brad sense). So, in motor control the role of "careful inference", guided by a specific philosophy, has to be much more significant than in other branches of science. In other words, without "theoretical motor control" – even cultivated by scientists commonly labeled "daydreamers" – any significant development (and, all the more, progress) seems to be hardly possible.

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