Chapter 6
Towards the Teaching of Motor Skills as a System of Growing Complexity

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Introduction

The twentieth century can be recognized as a period of "phase transitions" in science. Without being reductionist in the historical description, we posit that two events marked the scientific development on that period. The first event concerns the changes of classical Cartesian, Newtonian, or modern science to contemporary, new-paradigm, or systems science (Wiener, 1948). Classical science was based on the assumptions of simplicity, stability, and objectivity, which meant that, respectively, (1) from the parts, it would be possible to understand the whole; (2) the world would be stable, predictable, and reversible, with the possibility of control of phenomena; and (3) it would be possible to objectively know the world as it really is. Contemporary science, on the other hand, is concerned with complex phenomena that are apparently irreducible. It is based on the idea that a system tends to show new features not discernible from their units' components, but emerging from significant relationships between members of the team—that is, interaction (von Bertalanffy, 1952; Dupuy, 1996; Prigogine, 1997).

The second event is the change within the systemic thought from systems functioning based on negative feedback mechanisms to systems working based on the interplay of positive and negative feedback mechanisms. This change occurred during the second half of the twentieth century (von Foerster, 1960; Jantsch, 1980; Maruyama, 1963; Prigogine & Stengers, 1984; Weiss, 1967; Yates, 1987). This change was influenced mainly by applying of conceptions about thermodynamics of systems far from equilibrium and dissipative structures to living phenomena (von Bertalanffy, 1950, 1952; Schrödinger, 1945). This perspective brings about new themes such as order from noise, order by fluctuations, organized disorder,

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emergence, complexity, self-organization, chaos, and others as a basis of promising models that are oriented towards understanding and explaining phenomena from areas of knowledge, including educational ones (Chow et al., 2006, 2007; Koopmans, 2015; Steenbeek & van Geert, 2013; Stamovlasis & Koopmans, 2014). The present chapter was developed in this context.

We addressed questions on motor skills as a subject in education, their acquisition as the main goal for teaching/coaching, based on a nonequilibrium model of motor learning (Tani et al., 2014), which comprises two cyclical processes: functional stabilization towards a motor pattern formation whose structure reconciles order and disorder, and adaptation resulting in growing complexity.

Motor Skills as a Subject in Education

The motor skills phenomenon refers to those purposeful, efficient, adaptive, and learned movements that human beings have performed in order to survive (Corrêa, Walter, Torriani-Pasin, Barros, & Tani, 2014; De Paula Pinheiro, Marques, Tani, & Corrêa, 2015). The motor skills we are referring to here are those from sports, play, fight, dance, and exercise/gymnastics human cultural constructions, that is, which nowadays have been adapted and practised in order to fulfil biological, psychological, and social needs: health, competition, and leisure. For instance, while in the early days human beings threw darts, fought, and orienteered/navigated for utilitarian and survival reasons, today they do it to compete, improve health, and interact socially in their leisure time. It is through motor skills that human beings express their feelings and creativity and learn about themselves and the social environment in which they live (Tani, 1987). How human beings change their motor skills from one state of order to another thereby gaining in complexity poses an important question.

Due to the biological, psychological, social, cultural, and evolutionary roles that motor skills have had for human beings and their societies, they have been conceived of as part of the cultural heritage of many groups, which demonstrates their educational value (Tani & Manoel, 2004). To put it in another way, if sport, play, fight, dance, and exercise/gymnastics constitute sociocultural phenomena, enabling individuals to have access to them seems to be essential for certain educational processes. For example, in the school context, motor skills have been a subject because the knowledge related to them has been judged to possibly develop people's wellness and quality of life. It is thought that including motor skills in education allows individuals to do the following: (1) access and enjoy cultural heritage; (2) enhance and enrich their motor repertoire, which in turn improves interactions with the physical, social, and cultural environments in which they live; and (3) maintains and promotes health, providing them with opportunities to acquire knowledge, skills, and attitudes related to an active lifestyle (Tani & Manoel, 2004).

We suppose that in order for an individual to achieve the aforementioned educational goals, learning motor skills should occur by implementing three dimensions: the learning "of" motor skills, learning "through" motor skills, and learning "about" motor skills. The first refers to acquisition of ability to efficiently perform motor skills, the second is concerned with the acquisition of cognitive, affective and social skills by means of motor skills, and the third is related to the acquisition of knowledge about motor skills (Tani & Manoel, 2004). However, independently of the type of learning we believe that the teacher's knowledge about the nature of motor skills and on how they take place as a process of learning are a sine qua non of competence for effective teaching.

Motor Skills as a Complex System of Hierarchical Organization

There are a number of classifications of motor skills (Arnold, 1981; Fleishman, 1975; Gallahue, 2002; Gentile, 2000; Magill, 2000; Newell, 1989). For instance, they might be classified as open or closed according to their environmental stability; discrete, serial or continuous according to their starting and ending points and according to the order in which their components are performed; gross or fine according to the requirements of muscular groups and level of accuracy; closed or open circuit according to the use of feedback during or after execution; and cognitive or motor according to the demand for planning and memory. In fact, systems of classification for motor skills have not been made up as an end in themselves but as a tool for other purposes (Arnold, 1981).

For the purpose of the present chapter, motor skills are classified based on a systemic view of living phenomena (Laszlo, 2002), containing three important characteristics. First, motor skills can be conceived of as a complex system because in any level of analysis on which they are focused, they consist of the interaction of numerous components. A component refers to each part of a motor skill whose function in the skill as a whole is clearly identifiable (De Paula Pinheiro et al., 2015). For instance, in order to perform a pass in the game of futsal, an individual must integrate six components: (1) selecting a teammate target, (2) approaching the ball, (3) supporting a position with the non-kicking foot, (4) looking at the ball and holding the head steady, (5) contacting the ball, and (6) transferring weight forwards. Thus, we conceive motor skills as complex systems because they are emergent—that is, not discernible in their individual components but as a consequence of their interaction (Weiss, 1971).

A second important characteristic of motor skills is that they exist only in context. That is, motor skills involve a necessarily spatiotemporal relationship between performer and performance environment. This brings about a crucial implication for understanding the effectiveness of performances: the open nature of human beings. Similar to open systems, human beings interact continually with their environment, exchanging energy, matter, and information (von Bertalanffy, 1950, 1952). For instance, the selection, elaboration, and control of motor skills are made by continuous capture and utilization of environmental information.

An important theoretical issue related to the individual in a given environment is that the perception of environmental information is critical to the regulation of motor skills (Oudejans, Michaels, Bakker, & Dolné, 1996).

Finally, the third important characteristic of motor skills is that they simultaneously present consistency and flexibility. The first one is necessary to reliably reaches outcomes, and the second is essential for dealing with environmental instability (Bernstein, 1967; Cook, 1980; Glencross, 1980; Tani, 2005; Turvey, 1977). In the last few years these simultaneous characteristics have been explained by conceiving of motor skills as hierarchically organized systems with macrostructural and microstructural levels (Corrêa, Alegre, Freudenheim, Santos, & Tani, 2012; Corrêa et al., 2015; Corrêa, Davids, Silva, Denardi, & Tani, 2014; De Paula Pinheiro et al., 2015; Tani et al., 2014). The macrostructure refers to the motor skills' general spatiotemporal configuration, which emerges from the interaction between its components. It is constrained by the coupling of intention and task specificity, and it has been inferred based on relatively invariant measures of relative size, timing, and force, as well as sequencing.

The microstructure, in turn, refers to the components themselves. In complex open systems, the components simultaneously present autonomy and dependence because the macrostructure does not control the behavior of each part in detail but only constrains how they interact with each other (Lewin, 1999; Salthe, 1992; Waldrop, 1992; Weiss, 1971). As Laszlo (2002) writes, a macrostructure sets rules binding the parts among themselves. Thus, microstructure is responsible for the variability in the motor skills because of the performance options available within each component. The microstructure of motor skills has been accessed through measures of total movement time, overall force, and overall size.

In order to clarify the hierarchical organization of motor skills, let us consider the aforementioned example of the motor skills involved in futsal (Fig. 6.1): invariably, the numerous passes in a game of futsal are formed by the interaction

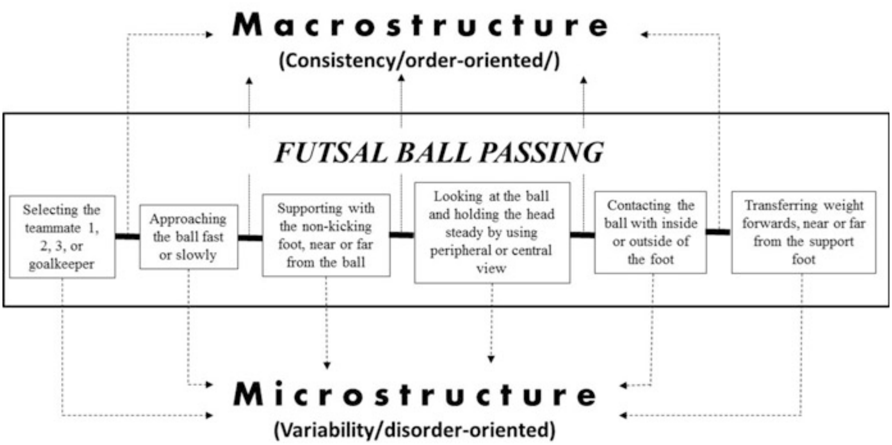

Fig. 6.1 Illustration of the hierarchical organization of passing of the sport of futsal

of six components mentioned above. This characterizes the macrostructure. Nevertheless, deciding which teammate to pass to, how fast to approach the ball, how to position the support foot, and which part of the body to touch the ball with vary according to the contexts of a game (e.g., displacement of teammates and opponents). One could say that such details emerge from specificity of context, which typifies the microstructure.

In sum, as a subject in education, motor skills can be considered as complex systems with a hierarchical organization. From this conception, the question we ask now is: what occurs when a given environment instability is greater than the flexibility of the skill microstructure? The answer to this question leads to the formulation of another important characteristic of motor skills: adaptability.

Motor Skills Learning as a Process of Growing Complexity

The currently adopted pedagogical models of motor skills can be characterized as equilibrium-oriented models. Equilibrium-oriented models explain the learning of motor skills as a process of reduction of inconsistency and incorrect responses through negative feedback mechanisms. The current movement pedagogy mainly emphasizes functional stabilization as a process of pattern formation and refinement (e.g., Mood, Musker, & Rink, 2012; Siedentop, 2009; Smith & Cestaro, 1998; Wrisberg, 2007). For instance, regarding the learning of futsal passing, teachers/coaches are advised to promote patterning in the interactions between the pass components through practice in a way the ball consistently reaches the intended teammate.

It is beyond doubt that the functional stabilization is a necessary state or condition for the life of human beings. One could say that its importance reflects the main definitions of motor skills: an acquired ability to achieve an environmental goal with the maximum certainty by organized and coordinated movements (Guthrie, 1952; Whiting, 1975). However, although models based on negative feedback mechanisms are able to explain the formation and maintenance of a stable pattern, they do not account for the open system nature of human beings, i.e., the adaptive human behavior.

This kind of system is able to become complex and elaborate by altering the content and organization of its contexts. This ability is possible because the system exchanges matter/energy and information with its environment (von Bertalanffy, 1950, 1952; Jantsch, 1980). Such exchanges allow humans to dismantle the acquired stability and change their internal state of organization. Thus, it is important to consider not only how human beings acquire and maintain stable patterns but also how such patterns are transformed into new ones—that is, adaptation.

From this perspective, a nonequilibrium view of motor learning has emerged as a promising alternative to elucidate the teaching of motor skills (Tani et al., 2014). It refers to an adaptive process model in which the acquisition of motor skills is considered as a cyclical and continuous process of stabilization and adaptation

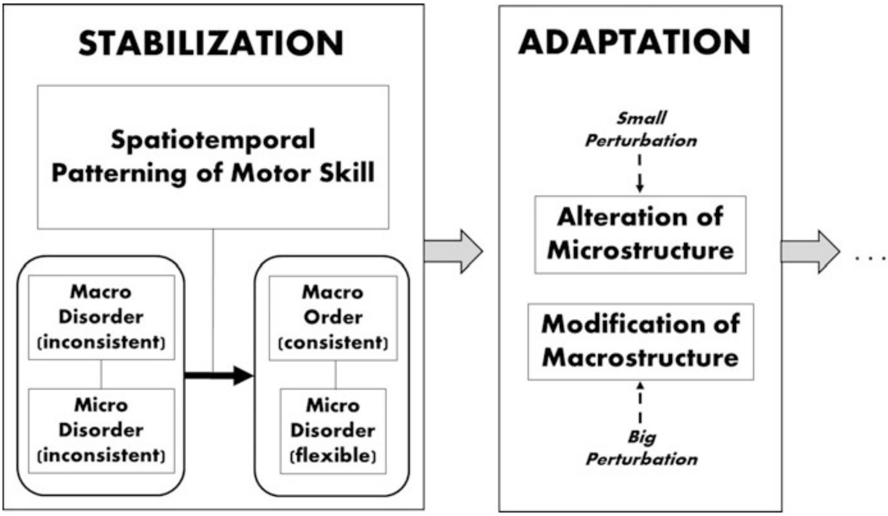

Fig. 6.2 Illustration of the nonequilibrium model of motor skill learning

(Fig. 6.2). The first refers to the functional stabilization phase that results in the spatiotemporal patterning of motor skills. As aforementioned, it occurs by mechanisms of diminishing errors and discrepancies (negative feedback), the main emphasis of the current pedagogical views.

However, as may happen in any open system, the acquired functional pattern may be perturbed by changes in the state of the individual (e.g., new intention), task (e.g., new rule), or environment (e.g., new space delimitation). In this case, the system functions based on influence of positive feedback (mechanisms of deviation amplification). Adaptation, the second learning phase, deals with how such perturbation can be used to reach a new stability regimen—that is, to generate order from disorder.

According to Tani et al. (2014), in order for adaptation to imply a new state of organization in the learning of motor skills, a reorganization of the acquired patterns in response to the perturbation must occur. For instance, in the game of futsal, those approaching a marking defender could require that a pass be performed faster. In this case, there would be the maintenance of stability since the perturbation would be eliminated by the system's flexibility (microstructure)—that is, by just altering a parameter (passing velocity). However, there may be a perturbation of such magnitude that would go beyond the reach of the system's flexibility. But the player could take advantage of it by reorganizing the skill structure. For instance, a shift in the velocity of approaching of a marking defender could make the player with the possession of the ball change the (1) support position from left to right foot and (2) contact the ball with the anterior instead of superior part of the foot. In this situation, the player would have changed two components in the skill structure. This has been named structural and self-organizational adaptation.

The main assumption here is that the reorganization of a previous structure into a new one implies growing in complexity, since it involves incorporating new information, components, and/or interaction modes (Tani et al., 2014) into existing structures. Furthermore, this growing in complexity also implies the acquisition of redundancy as an increase in the availability of resources to deal with perturbations (De Paula Pinheiro et al., 2015). Based on these statements, it seems reasonable to propose that the teaching of motor skills should be directed at adaptation of motor skills.

Final Remarks: Insights on the Teaching of Adaptation

As we wrote previously, motor skills are genuine educational content because they represent a significant part of the legacy of knowledge built by humankind throughout our existence. Motor skills are among the means by which humans interact with their environment by exchanging energy and information, which allow them to prevent an increase in entropy, remain in a state far from equilibrium, and develop towards growing complexity (Schrödinger, 1945). In sum, motor skills are the essence of life.

From the importance of motor skills as a subject in education, the comprehension of the open nature of humans and their capacity to continually learn allows us to conceive of learning as an adaptive process—that is, as continuum that involves cycles of functional stabilization and adaptation. The main assumption here is that the realization of each cycle implies states more complex of organization.

In this process, the basic question is: what kind of pattern or structure should be formed to account for the perturbation, or what type of competence is required from the motor system for perturbation to become an agent of change towards complexity? In response to this question, we have proposed that motor skills cannot be represented as a fixed pattern but as a pattern that reorganizes itself in the context of a new learning process. In other words, motor skills need to have some degree of stability, but they can reconstruct themselves through perturbation when they are destabilized. For this purpose, we have proposed that motor skills are organized hierarchically at the levels macrostructure and microstructure (Tani et al., 2014).

This view brings two main practical implications for teaching. First, teachers should emphasize the skill rather than technical. The technical has been considered as that best way to perform a motor action. It is closely related to rigidity and details in the performances. For other hand, the skill is related to efficiency in achieving goals, regardless of the form it occurs. Second, it seems crucial that teachers have clear how motor skills are composed, that is, which are their components (microstructure) and how are their interaction modes (macrostructure). For instance, while a pass of the sport of futsal and a spike of the sport of volleyball are open and discrete motor skills formed, respectively, by six and four components interacting sequentially, the front crawl and backstroke swimming refer to the closed and continuous motor skills, formed by three components that occur simultaneously. In the first example, instructional emphasis for formation of macrostructure should be on sequencing (e.g., running, jumping, hitting, and landing, for the volleyball spike). And, in the second example, the instructions should focus on the simultaneousness (e.g., breathing while perform the arm and leg strokes, for the backstroke swimming).

Furthermore, in order to manipulate the skill to cause adaptation teachers might change its spatial and/or temporal physical dimensions. For instance, temporal modifications (e.g., from faster to slower running) imply a low requirement for adaptation; spatial alterations (e.g., from larger to smaller steps during a running) imply moderate demand for adaptation; and spatiotemporal modifications in the skill (e.g., from larger and faster to slower and smaller steps during a running) imply higher requirements for adaptation (Corrêa, Ugrinowitsch, Benda, & Tani, 2010).

From this perspective, besides the structure of motor skills, factors related to disorder (e.g., uncertainty, variability, and error) should be considered by teachers in conjunction with others associated with order (e.g., information, consistency, and regularity) in order to promote the formation of a skill that contains both consistency and variability. This proposition has been supported by studies on practice schedule (Corrêa, Benda, Meira, & Tani, 2003; Corrêa et al., 2010; Gonçalves, Santos, & Corrêa, 2010). They have shown that the preceding skill structure might be formed from a combination of constant and varied practice schedules. According to these studies, the regularity of the constant regimen provides the formation of the macrostructure by patterning the interaction modes among the components. Also, the posterior varied condition increases the flexibility of the microstructure. Importantly, this proposition have been supported by studies with children, adults, and elderly (Gonçalves et al., 2010). Thus, teachers could organize practice initially in a constant way, and then in a varied regimen.

In order to adopt an ideal combination of constant-varied practices, teachers should consider the concept of self-organized criticality. When a system has self-organized criticality, it has achieved a degree of organization which places it at the border of chaos—prompting for creation, innovation, and/or evolution (Langton, 1992; Packard, 1988). This refers to a state in which a system reaches critical values that make it able to change; or, to a point of transition between order and disorder in which a small stimulus can generate a large change (Bak & Chen, 1991; Bak, Chen, & Creutz, 1989).

Recent evidence has shown that there is an optimal amount of constant practice to form the skill macrostructure (Corrêa, Barros, Massigli, Gonçalves, & Tani, 2007; Corrêa, Gonçalves, Barros, & Massigli, 2006; Corrêa, Massigli et al., 2010). These studies have shown that a minimum amount of practice is enough to prepare a motor skill for diversification. Furthermore, other evidence has shown that there is an optimal level of variability that provides the required flexibility for motor skill adaptation (De Paula Pinheiro et al., 2015). Thus, in order to develop ability for adaptation, teaching could involve the minimal amount of constant practice for macrostructure formation (e.g., until a pattern to be observed), and the minimal quantity of items in varied practice for skill diversification (e.g., three parameter values).

Finally, another important insight from the adaptive process studies is that the individual capability of the students should be considered in the practice schedule. Specifically, adaptation is beneficed when learner is provided with moderate freedom of choice in practice during the stabilization phase. According to Walter, Bastos, Araujo, Silva, and Corrêa (2008), constant practice with some freedom in the choice of components allows the learner to perform a sequence of movements more comfortably. It appears that the prior establishment of some components allows the learner understands the skill's macrostructure. Conversely, the freedom to choose some components enables the formation of flexible strategies, i.e., relative to the microstructure of the skill. For instance, considering the skill structure of the futsal passing previously described (Fig. 6.1), teachers could instruct the learner in relation to sequencing, selecting a teammate, and approaching the ball. Consequently, learner would choose how to perform the other components.

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