Nonlinear learning underpinning pedagogy: Evidence, challenges and implications

Abstract

This paper provides a brief overview of the framework of Nonlinear Pedagogy and evidence emanating from motor learning literature that underpins a nonlinear pedagogical approach. In addition, challenges for Nonlinear Pedagogy and a discussion on how Nonlinear Pedagogy support the work of Physical Education (PE) teachers will be shared. Evidence from the increasing volume of work on nonlinear learning from motor learning literature is used to suggest how acquisition of movement skills is supported by nonlinearity. The emergence of goal-directed behaviors is a consequence of the performer, environmental and task constraints. With a nonlinear pedagogy approach, the focus is on the individual learner where opportunities for meaningful actions can be learnt. Design principles based on representativeness, focus of attention, functional variability, manipulation of constraints and ensuring relevant information-movement couplings can be delivered via pedagogical channels of instructions, practices and feedback to the learners. Importantly, this focus on the individual sets the foundation for a developing nonlinear pedagogy framework to enhance teaching in PE although the challenges are non-trivial.

Key words: Nonlinear learning; design principles; nonlinear pedagogy; skill acquisition

Nonlinear learning underpinning pedagogy: Evidence challenges and implications

The Call for Understanding Nonlinear Learning

The approach in which practitioners undertake coaching or pedagogical practices has immense impact on how individuals learn movement skills (Renshaw, Davids, & Savelsbergh, 2010). It is therefore not surprising that a large number of empirical investigations have been conducted to determine how best to deliver coaching or teaching to maximize skill acquisition in PE and sports. Importantly, the role of human movement science is paramount in advancing the knowledge on the beneficial methods and approaches that practitioners can embrace to enhance learning and performance among elite and recreational athletes.

Advancement in the motor control and learning literature under the umbrella of human movement science over the last decade has further provided strong evidence to underpin pedagogical approaches that account for the dynamism and complexity which are inherent in learning movement skills (see Davids, Button, & Bennett, 2008; Davis & Sumara, 2006; Ovens, Hopper, & Butler, 2013; Renshaw et al., 2010). There is increasing acceptance that individual differences among learners need to be accounted for when practitioners plan teaching interventions in any learning contexts (Chow & Atencio, 2012). The focus is on the individual and pedagogical practices will have to cater to the dynamic and complex interactions that occur between learners, the task and the environmental constraints (Chow, Davids, Hristovski, Araújo, & Passos, 2011; Renshaw et al., 2010). The study of how the individual learner behaves and alters behavior is nested in a situated environment where these complex interactions among constraints occur (Chow, 2010; Jess, Atencio, & Thorburn, 2011). The argument is that adaptive, goal-directed behavior emerges as neurobiological systems attempt to satisfy these interacting constraints. Appropriately, ecological dynamics proposes that the study of neurobiological cognition and action should avoid ‘organismic asymmetry’ (Dunwoody, 2007) and instead should be targeted at "...phenomena within the organism-environment synergy rather than within the organism per se." (Turvey & Shaw, 1995). When we examine the learner as being situated within the environment, important insights on how learners establish important information-movement couplings can be better understood. Such complexities present in behavioral changes provides a strong call to see learning as nonlinear where sudden transitions between various movement patterns and emergence of new coordination is typical rather than atypical in learning contexts (see Chow et al., 2011, Newell & Liu, 2012). As further pointed out by Hmelo-Silver, Marather and Liu (2007), the principle of emergence is omnipresent in complex systems and the outcomes are not predetermined. These phenomena are hallmarks of a complex system and are evidence of nonlinear learning, underpinned by a dynamical systems theoretical framework (Davids et al., 2008).

Non trivial questions pertaining to how nonlinear learning is relevant have been previously raised that needs to be addressed. For example, what is a nonlinear pedagogy approach? What are the design principles from a nonlinear pedagogy that can be used to support instructions, practices and feedback? What are the challenges facing practitioners who want to adopt a nonlinear pedagogical approach? Last but not least, what are the practical implications (teaching and research) for delivering such a nonlinear pedagogical approach in a school context?

In this paper, a brief review of a Nonlinear Pedagogical approach will be undertaken from the increasing amount of work published on this topic in recent years. In addition, evidences for nonlinear learning from the motor learning literature and challenges on using such an approach will be discussed. Importantly, additional insights will be shared on the implications for adopting a nonlinear pedagogy approach in physical education.

What is Nonlinear Pedagogy?

More than a Constraints-led Approach

There is adequate evidence to support that human learning is nonlinear in nature and therefore, teaching and coaching should account for such nonlinearity (see Chow & Atencio, 2012; Tan, Chow, & Davids, 2012). Based on ideas from Newell (1986) and Davids et al. (2008), a Constraints-led approach has been vigorously presented to promote the understanding of how goal-directed behavior can emerge as a consequence of the interacting constraints (task, environment and performer) in a learning or performance situation (see Renshaw, Chow, Davids, & Hammond, 2010 for a comprehensive discussion on a constraints-lead approach). Specifically, performer constraints refer to the structural and functional aspects of the learner; environment constraints incorporate the physical and the social-cultural environment and rules of game, equipment and goals of the task can be categorized as task constraints (Davids, et al., 2008). According to Renshaw et al. (2010), an embodied model of motor learning (Port & van Gelder, 1995) such as a constraints-led approach views mind, body and the environment as continuously influencing each other to shape behavior. From this perspective, motor learning is a process of acquiring movement patterns which satisfy the key constraints on each individual (Renshaw, Davids, Shuttleworth, & Chow, 2009).

However, a Constraints-led approach only promotes the understanding of how skills is acquired from a motor learning domain and does not provide a framework for designing motor learning programs. A *Nonlinear Pedagogy* approach, based on nonlinear and complexity phenomenon, has increasingly been advocated to provide practitioners with key principles to underpin teaching. Pertinent information on how to assess performance, how to structure practices, and how best to deliver instructions and provide feedback are particularly relevant (see Chow, Renshaw, Button, Davids, & Tan, 2013; Ovens, Hopper, & Butler, 2013). Nonlinear pedagogy emphasizes the need to design representative and facilitative type of learning for individual learners supported by principles in understanding the nonlinearity features of human learning. Recent work in nonlinear pedagogy has demonstrated that the theoretical principles underlying nonlinear pedagogy can be adopted to address the key question, ‘What design principles can be used to support teaching and learning in PE?’ (see Chow et al., 2009). Below, key design principles from a Nonlinear Pedagogy approach are discussed.

Design Principles in Nonlinear Pedagogy

Situated for representative learning design.

Nonlinear Pedagogy provides a pedagogical framework where learning needs to be situated in real-game contexts (Chow, 2010). Port and van Gelder (1995) have emphasized the importance of understanding the development of cognition from a situated and embodied perspective. Learning takes place when the learner is in the context of the learning environment and the acquisition of knowledge occurs as a consequence of the interactions between the learner and the environment. Barab, Cherkes-Julkowski, Swenson, Garrett, Shaw & Young (1999) further stressed the role that the environment play in providing sources of information in the form of material content, patterns and invariant properties which allows learners to construct meaningful relations. Davis and Sumara (2006) even suggested that pupil learning should occur in a “bottom up” manner reflecting higher levels of situated and authentic learning with the focus on students.

Fajan et al. (2009) reiterated the relevance of providing representative learning situations by highlighting that athletes need to be placed in realistic learning environment so that they can attune to information which will enable them to make intelligent and informed decisions based on their own, team mates' and opponents' action capabilities. Renshaw (2010) in his discussion on backyard games interestingly highlights the relevance and situated benefits of having young children involved in such informal games but yet, rich in the numerous learning opportunities for them to establish meaningful affordances in a game context (also see Chappell, 2004).

Developing relevant information-movement couplings.

Based on ideas from Ecological Psychology (see Gibson, 1986), Renshaw and colleagues (2009) have highlighted the importance of environment mutuality and the circular relationship of perception and action in the acquisition of goal-directed behaviors. The need to establish functional information-movement couplings in learning movement skills is one of the corner stones of a nonlinear pedagogical approach (Chow et al., 2007). This circular relationship between information and movement is key to understanding the concept of *affordances* and its' role in movement control. Affordances are opportunities for action and are defined relative to the action capabilities in relation to the individual (Fajan, Riley, & Turvey 2009). The focus is on the *individual* and how opportunities for action are pegged to the individual as he or she operates within an environment (social or physical) (see Kulikowich & Young, 2001). Nonlinear Pedagogy leverages on the importance of establishing functional affordances and such opportunities for action can be meaningfully created when the learners are placed in representative in-situ learning contexts that mimic the real game situations.

Manipulation of constraints.

The role of constraints has been put forth as an important aspect of nonlinear pedagogy. While much has been written about the Constraints-led approach and its' role in skill acquisition (see book by Renshaw et al., 2010), it only provides an understanding of how goal-directed behavior occurs. Nonlinear pedagogy is underpinned by this understanding of how key constraints interact with each other for coordination to self-organize in a performance or learning setting. Constraints is defined as providing the boundaries where the learners can explore and search for movement solutions afforded to the individual within a perceptual-motor workspace (see Chow et al., 2006; 2007 for further discussion on constraints).

Typically, task constraints like instructions, rules of the activity and equipment can be readily manipulated to perturb learners to explore and acquire different movement behaviors (Chow & Atencio, 2012; Tan et al., 2012). Numerous examples have been provided in previous papers (see Chow et al., 2007; Renshaw et al., 2010; Tan et al., 2012) about features of nonlinear pedagogy on how intervening task constraints can channel learners to exhibit varied movement behaviors (e.g., encouraging the short and long play in badminton by altering the width of the playing area; changing the characteristics and size of soccer balls; adjusting the height of the volleyball nets for the dig and set passes). The manipulation of constraints by the coach or teacher is also a powerful aspect of nonlinear pedagogy in encouraging transitions and acquisition of new preferred stable movement behaviors in a learning system.

Exploratory learning: Leveraging on functional variability.

An important aspect of nonlinear pedagogy is associated with the role of functional movement variability in enhancing acquisition of coordination since movement variability is seen as a feature of nonlinearity in human learning (Chow & Atencio, 2012; Chow et al., 2011). ‘Noise’ amplifies the exploratory activity and may guide the learner to discover individualized functional solutions to a specific task goal (Newell et al., 2008; Schöllhorn, Mayer-Kress, Newell & Michelbrink, 2009). Nonlinear pedagogy incorporates and recognizes the critical role of infusing perturbation (e.g., in the form of encouraging variability in practice conditions) in a learning environment to allow for exploratory learning and greater search in the perceptual-motor workspace of the individual. This is especially relevant when a learner is stuck in a rut and the coach can incorporate a perturbation to the practice by altering task constraints such as instructions or equipment to challenge the learner to try new coordination patterns.

Reducing conscious control of movement: A role for attentional focus

Another aspect of nonlinear pedagogy involves the impact of instructions based on an external focus of attention that seems to reduce conscious and explicit control of movement. Wulf (2007) described an external focus of attention as “*where the performer’s attention is directed to the effect of the action”*, compared to an internal focus of attention, “*where attention is directed to the action itself*”. Instructions to learners can be varied by guiding them to focus attention on either the effects of a movement on the environment (i.e., the outcomes of an action) or on body movements (i.e., limb segments) involved in producing an action, respectively (see Peh, Chow, & Davids, 2011 for a review). According to Bernstein (1967), with increasing sophistication of performance, responsibility for coordination and control is delegated to subordinate levels of the Central Nervous System, allowing learners to harness the self-organising movement-system dynamics that meets the task goal. In designing successful learning experiences from a nonlinear pedagogical perspective, self-organising processes should be exploited and the use of an external focus of attention on movement effects seems to encourage such processes.

However, it should also be noted that many of the previous findings on the impact of different attentional focus of attention instructions have greater relevance to skilled participants for various movement tasks. Novices and children may respond differently to the presentation of external focus of attention instructions and the perceived benefits of such instructions may not be as convincing. For example, Beilock, Carr, MacMahon and Starkes (2002), whose work on the explicit monitoring hypothesis (which hypothesizes that pressure causes increased attention to a skill-focused process that disrupts performance for proceduralized skill), highlighted how performance outcome could be better for novices when using an internal focus of attention. Thus, the benefits of external focus of attention instructions can also be task or even learner dependent (Peh et al., 2011).

What does this mean for the Teacher and Learner?

In brief, the focus of nonlinear pedagogy is on the individual learner and clearly, student-centric (see Figure 1 for a conceptual visualization of a Nonlinear Pedagogy approach). The recognition is that learners should be given the opportunities to acquire movement solutions that are individualized based on the learning and performing context. The interaction of performer, environment and task constraints takes into account the dynamic influences that each has on the individual. Encapsulating these constraints, practitioners could develop design principles that incorporate representativeness, manipulation of constraints, attentional focus, functional variability and the maintenance of pertinent information-movement couplings. These design principles can then be delivered through the key pedagogical channels of instructions, practices and feedback to allow functional goal-directed behaviors to emerge. Nonlinear pedagogy thus has the potential to provide the design principles and mechanisms that underpin learning activities that is situated in real performance context and suitably catered to the individual learner.

Insert Figure 1 about here

Evidence and Challenges for Nonlinear Pedagogy

Evidence from Motor Learning Investigations

The support for a nonlinear pedagogy approach is based not solely on theoretical discourse over the last decade. Empirical evidence from motor learning investigations has been slowly accumulating in recent years to argue for a strong case for nonlinear pedagogy. Chow et al. (2011) in their paper highlighted numerous evidences of such a nonlinear pedagogical approach. Below, recent work pertaining to the use of instructions and organization of practices will be briefly discussed to further strengthen the basis for nonlinear pedagogy.

Primarily, motor learning studies focuses on examining how learner solve the degrees of freedom (dof) problem as termed by Bernstein (1967). The numerous movement possibilities offered by the human movement system presents a problem in control while at the same time, it affords the learner a vast array of movement solutions to meet a movement task requirement. From a dynamical systems perspective, coordination is seen as mastering the degrees of freedom and the presentation of instructions and nature of practice has a strong influence on how coordination is acquired by the individual (Chow et al., 2009).

The focus on individuality to examine learning and how task properties can influence functions of learning have been well documented by a series of works by Newell and colleagues (see Newell & Liu, 2012). While the power law as a function of learning has been previously accepted as typical, a comprehensive review of data pertaining to motor learning studies (e.g., cigar rolling in Crossman, 1956 and maze drawing task in Snoddy, 1926), Newell and Liu (2012) does suggest that a closer examination of multiple time-scales of change in task outcome may indicate other possible functions of learning (e.g., exponential or S-shaped learning curves). In addition, the focus on examining learning should be on the individual and that averaging data can mask the actual change in the performance dynamics of learners that make up the averaged group function which incidentally is commonly used to assess the function of learning (Liu, Mayer-Kress, & Newell, 2003). Such findings from motor learning literature lends strong support to the relevance of focusing on individual learning and recognizing that there may be varied pathways to learning movement behaviors, which underpins a nonlinear pedagogical approach.

Exploratory behavior has also been deemed to be an inherent feature for successful learning for movement skills (Chow et al., 2006). Increasingly, more evidence from motor learning literature suggests that such exploratory behavior is critical to allow learners to establish effective affordances in real sports performance settings. Hristovski, Davids, Passos and Araújo (2012) recently highlighted how creativity in problem solving can exist in a self-organizing performer-environment system in relation to sport performance. It was suggested that when constraints are relaxed, exploratory behavior can be enhanced which in turn allows for greater fluency and flexibility in discovering atypical but yet functional movement solutions to a task goal (Hristovski et al., 2012). Using an example from a heavy-bag punching task in boxing, Hristovski et al. (2012) discussed how different punching actions are afforded to the individuals at various performer-target scaled distances. Importantly, it was deduced that the hierarchy of nested dynamic states (i.e., different punch actions like a jab, hook or cut) are very sensitive to changes in constraints such that novel punching actions can emerge when performer-target scaled distances are manipulated (Hristovski et al., 2012). Further evidence from Pinder, Davids, & Renshaw (in press) on examining cricket batting determined that careful manipulation of ball pitching location (bounce point) can create a situation where the batters may be forced into a region of great uncertainty for response organization. Such meta-stability created within a movement system property was found to allow the batters (when poised between multiple co-existing states) to generate flexible and more varied functional movement patterns.

More recent work by Seifert and colleagues (see Seifert & Davids, 2012; Seifert, Wattebled, L'Hermette, & Hérault, 2011) on examining the role of functional movement variability in ice-climbing and breast stroke swimming also yielded interesting evidence to support its role in enhancing skill acquisition. In ice-climbing, it was found that expert climbers demonstrated greater levels of variability in upper and lower limb coordination patterns. This higher level of variability allowed the expert climbers to explore a larger range of movement behaviors that are functional for accomplishing the ice-climbing task (Seifert & Davids, 2012). It was also reported how expert swimmers showed more adaptability by varying the arm-leg coordination within a stroke cycle and swim speed to perform more effectively for the breast stroke (Seifert & Davids, 2012). Another interesting study on spring board diving among elite divers by Barris, Farrow and Davids (in press) also highlighted the pertinent role that variability plays to allow for adaptability and flexibility even at the elite level for a closed skill. While the global topological characteristics of the diving action among the elite divers are similar, there were still differences in movement patterns at key events during the approach of the dive. Barris et al. (in press) suggested strongly that such functional variability is critical for the divers to make subtle but key adaptations for successful performances. As an advocate for infusing variability in practice, Schöllhorn and colleagues (Schöllhorn et al., 2009; Schöllhorn, Hegen, & Davids, 2012) exemplified such functionality of variability with the idea of a *Differential Learning* approach where learning can be enhanced when learners are required to perform different variations of the intended movement (e.g., in soccer, speed skating) although more research into the feasibility of this approach requires further investigation.

Relevance of Nonlinear Pedagogy to Existing Pedagogical Practices

Although there is clearly no one best way to teach (see Metzler, 2011), nonlinear pedagogy can provide the scaffold and theoretical framework for researchers and practitioners to develop effective learning designs. Current pedagogical practices that are commonly used in pedagogical settings actually incorporate some aspects of nonlinear pedagogy to varying extent.

In the physical education literature, constructivist approaches have conceptualized students as active learners, with individual needs, and teachers as facilitators in physical education (Lee 2003). More recently, there has been greater emphasis on how learners individually construct their knowledge in relation to their learning environment and moving away from the 'process/product' paradigm (Richard & Wallian 2005). Pedagogical approaches such as Teaching Games for Understanding (TGfU) (Thorpe & Bunker, 1989) and Situated Learning (Rovegno, Nevett, Brock, & Babiarz, 2001) are just some examples underpinned by a strong constructivist orientation and these pedagogical approaches incorporate key aspects of nonlinear pedagogy (Chow et al., 2007). For example, manipulating task constraints is a common pedagogical practice present in many pedagogical settings used by teachers to create learning situations for students. In TGfU, key pedagogical principles such as sampling, task complexity, representation and exaggeration can be underpinned by the pedagogical mechanisms inherent in nonlinear pedagogy (Tan, Chow, & Davids, 2011). Manipulating rules, equipment and playing areas can create modified game settings where certain tactical concepts can be sampled, represented or even exaggerated. From a TGfU approach, such introductory games afford the creation of representative and situated learning contexts for which the learners can be challenged to establish important information-movement couplings that are realistic (Chow & Atencio, 2012; Tan et al., 2011).

Over the last 30 years, motor learning principles based on an information-processing perspective, which focuses on the construction of knowledge by the learner without accounting for important dynamic environmental-performer interactions, has dominated and supported most pedagogical practices in learning settings (Chow et al., 2007; Tan et al., 2011). However, theoretical advances in complexity theory and understanding of learning from a nonlinear perspective have strengthen the case for motor learning to be seen as a more complex, ecological and nonlinear process. Not surprisingly, many motor learning principles situated within pedagogical settings actually contain aspects of nonlinear pedagogy. Increasingly, a nonlinear pedagogy approach can be used to support existing motor learning principles. For example, the infusion of variability in practice (e.g., incorporating random or variable practice schedules instead of blocked or constant practices), is also one instance where existing motor learning principles are commonly included in pedagogical settings. Task simplification, which is considered a part practice approach, also harnesses the principle of manipulating task constraints to create learning situations where learners can acquire a movement in a simplified form without compromising on pertinent information-movement couplings inherent in the movement (Davids et al., 2008).

Key Challenges in Implementing a Nonlinear Pedagogical Approach

As with all forms of teaching approaches, there will be challenges on how researchers and practitioners implement the approach. Below, a few issues that need to be addressed when implementing Nonlinear Pedagogy are highlighted.

Question of time.

Exploratory learning can be time consuming and time allocated for PE in a school curriculum is very valuable for teachers and students. Critics may argue that while learning may take on a nonlinear pathway, the use of more prescriptive learning could ensure that the learners are actually practicing what is required or expected. If the solution pathway is pre-determined, less time will be required for any form of exploratory learning and perhaps, learning objectives can be more quickly achieved. This certainly addresses the need to see 'results' from less time spent on practice.

However, a key question that emerges is if these results are actually desired? A movement behavior should be well-learnt and most importantly, functional and individualized in actual game performance contexts where the affordances are effective. A prescribed movement solution may not be as easily attainable or even functional for the individual. While a top-down approach (i.e., teacher centered) saves time, it may not necessarily be best for learning. The expectation of all learners acquiring a certain optimum movement solution is unrealistic (Davids et al., 2008). If the right task constraints are manipulated, exploratory learning can be properly channeled for functional movement solutions to emerge.

Level of expertise and competency of practitioner.

When learning of movement skills is to be situated within a game setting, it throws up significant challenges for the practitioners because in a game situation, many opportunities for actions are available and varied movement game play patterns may emerge as a consequence of the dynamic interactions among constraints. This in turn creates a huge pressure on the practitioner to be able to identify coachable or teachable moments. In addition, the coach or teacher needs to know how to manipulate appropriate task constraints to encourage the emergence of desirable movement behaviors that are individually functional. There is no denying that to adopt a nonlinear pedagogical approach to coaching and teaching, the practitioner needs to be competent and well versed in the dynamics of the sport. With the right level of skill expertise and competency, the practitioner can more effectively manipulate relevant task constraints to channel learners to explore meaningful perceptual-motor workspace to achieve success in meeting the task goal. This can be challenging for beginning practitioners or those with less expertise in the sport that they are attempting to coach or teach. Greenwood, Davids and Renshaw (2012) appropriately stressed that high level coaches and athletes have relevant experiential knowledge that can be used to inform empirical investigations on enhancing sports performance. Taken in a similar light, such experiential knowledge would potentially be relevant for practitioners to maximize learning opportunities. When practitioners share valuable insights on the dynamics present in successful movement behaviors, performance levels in their athletes can be increased. In turn, practitioners with inadequate competency will not be able to manage the intricacies and dynamism present in coaching/teaching underpin by a nonlinear pedagogical approach.

Real impact of complexity thinking in Nonlinear Pedagogy.

The understanding and acknowledgement that learning is nonlinear is increasingly gaining acceptance. Researchers and practitioners seem to recognize that coaching/ teaching approaches need to account for such nonlinearity. However, acceptance is only one aspect of the story and the actual delivery of such a nonlinear or complexity based pedagogy may not materialize for many different reasons.

Critically, Tinning and Rossi (2013) shared how physical educators in the schools are consumed by the comfort of knowing that they are in control for more ‘linear’ approaches even though they may accept that nonlinearity is a central feature of learning. This linear perspective has been institutionalized and accepted as a way of teaching (or even coaching!) since the expectations for practitioners when they teach, is for predictable learning outcomes to surface (Tinning & Rossi, 2013). Thus, it is difficult for practitioners to relinquish ‘control’ to accept that effective learning from a nonlinear pedagogy can and should tither on the edge of chaos. As appropriately indicated by Tinning and Rossi (2013), the need to account for learning with pre-set objectives from the learning activities overrides the potential that a nonlinear pedagogical approach based on complexity theories offer to these practitioners. Gough (2010) even suggest that complexity thinking could be better accepted as a ‘metaphor’ to guide teaching (i.e., a complexity way to think about PE pedagogy). Some researchers and practitioners may also argue that there are no extra benefits of ‘understanding’ nonlinear learning if in their perception, learners are still learning and they can continue to be accountable to their organizations. Moreover, some practitioners may also suggest that some aspects of nonlinear pedagogy are already present in their existing repertoire of teaching approaches (e.g., adding variability and modifying equipment). So, is this something new and useful or is this understanding of nonlinear learning just the ‘same old’ but articulated in a different way? These are real issues in acceptance that coaches and teachers grapple with when presented with an option to teach in a nonlinear approach.

It is natural for practitioners to hold on to existing practices that seemed to serve them well and some may become deeply entrenched in the beliefs of how those practices work. It is not the purpose of this paper to specifically argue that nonlinear pedagogy is the better approach, it is just that using a pedagogical approach that adequately accounts for individual differences, situated and encouraging exploratory learning is something worth exploring when evidences to support such a pedagogical approach from motor learning literature is strong. So, even if practitioners are already using some aspects of nonlinear pedagogy in existing pedagogical approaches, a clearer understanding of nonlinear learning can equip these practitioners with a more structured approach to design and deliver instructions, feedback and practices (i.e., pedagogical channels).

Conducting Research and Practice

While the evidences from the motor learning literature are strong, what does it mean for researchers and practitioners who are keen to explore the use of a nonlinear pedagogical approach in their empirical investigations or teaching? It must be acknowledged that much of the literature offered as evidence so far has been derived from elite sports rather than from schools. A nonlinear pedagogy approach should be framed as a work in progress that offers immense potential for enhancing teacher education in the 21st century. Here, some ideas are shared on how researchers and practitioners can adopt a nonlinear pedagogical approach in their respective work.

Focus on Process rather than Outcome

One of the key approaches to investigating nonlinear pedagogy is to ensure the research designs are ecologically valid and situated in a context where learning can be teased out effectively (Chow et al., 2007). The focus should be on examining the teaching and learning processes that are present and not just about comparing between a typical teaching approach versus an exploratory, nonlinear pedagogical approach. Many past studies have compared different instructions that are generally prescriptive and drill-like to teaching methods that are explorative. For example, instructional studies have compared skills versus games for understanding approach (Allison & Thorpe, 1997), strategy-oriented versus traditional (Blomqvist, Luhtanen, & Laakso, 2001), skill teaching versus mastery learning (Harrison, Preece, Blakemore, Richards, Wilkinson, & Fellingham, 1999), scaled versus adult size equipment (Farrow & Reid, 2010), analogy versus explicit instructions (Liao & Masters, 2001), external versus internal focus of attention (Wulf et al., 1999). While these studies have provided valuable insights into the effectiveness of various teaching approaches, the over-emphasis on comparing teaching approach A against approach B have blinded researchers from examining more meaningful information about the processes present in these different approaches. For example, Gray and Sproule (2011), in their investigation on the effects of a tactical teaching approach in a Scottish school, stressed the importance of examining the teaching and learning processes rather than just outcome of different teaching approaches. Perhaps, a more in-depth investigation on the strengths of different approaches and teasing out elements of nonlinear pedagogy present in these pedagogical practices can be more meaningful. Taking a leaf from the work by Kapur (2012) who investigated the efficacy of a Productive Failure pedagogical approach in learning the concept of variance in mathematics among secondary school students, the focus was on determining aspects of a learning design that encourages learners to experience 'failure' but yet became more adept at conceptual understanding and transfer eventually. The study did not strictly set out to compare if one pedagogical approach (Productive Failure) was better than the other (Direct Instruction). Rather, the emphasis was on examining the key processes of learning and how critical aspects of a Productive Failure approach were evident across both the Direct Instruction and Productive Failure interventions.

In relation to the PE context, capturing movement data (i.e., coordination) coupled with performance outcome changes as a consequence of teaching can tell us a lot more about the processes that are meaningful for learning. For example, if both traditional and a more exploratory teaching approach can yield similar performance outcomes after a series of practices or lessons, what is the pathway of change in terms of coordination? Are there more movement solutions afforded by learners from a nonlinear pedagogical approach? Referencing to the earlier discussion on the need to focus on the individual to examine learning, would it be more realistic to expect that a nonlinear pedagogical approach provide learners more opportunities for individualized movement solutions and still achieve success in meeting the required task goal? These questions highlight pertinent implications for the need to examine processes rather than just outcome for learning.

Use Quantitative and Qualitative Analyses

Harness the availability of video technology and motion tracking systems to examine change in behaviors together with outcome changes can provide objective and quantifiable data to determine learning. Advancement in technology has increasingly avail researchers to useful information relating to movement behavior changes. For example, the use of a motion tracking system (A-Eye) (Barris, 2008), which is a simple software that captures displacement data of individuals in a playing area, can allow sports scientists to examine game play behaviors of players at different skill levels and for different games (see Barris & Button, 2008). Such technology can be easily introduced in a sport setting or even in a school to capture movement behaviors or patterns of play among learners in a team game. However, the practitioner must have the necessary knowledge to determine the key variables that could be relevant to answer interesting pedagogical questions from the use of such technology. For example, the teachers may need to work with researchers with a strong knowledge on nonlinear pedagogy to use the technology to meaningfully determine changes to playing patterns and therefore obtain an insight to how learners acquire an increased awareness of tactical knowledge. In addition, variables from a sport setting like stretch indices that gives an indication on the spread of a team, distance of players to ball and even a team geometric centre that provides a median point about the movement of the team collectively in invasion games can be relevant as markers of behavioral change (see Bourbousson, Seve, & McGarry, 2010). Coupled with qualitative data through small group discussions or interviews with learners, much information can be elicited to inform the researchers about the processes that can enhance or impede learning. Such a comprehensive approach (encompassing both quantitative and qualitative analyses) lends support to examining the dynamic interactions that will occur in a representative learning context as purported by a nonlinear pedagogical approach.

Emphasize Representative Learning Designs

Structure learning activities based on in-situ contexts that are representative of how the game skills will be used on actual or modified game settings. Passing in soccer for example should be practiced in the presence of defenders and under game rules that mimic most aspects of the game. Similarly, shooting in basketball should be undertaken with an opponent attempting to block the shot. Devoid of any defenders or structured in a contrived manner will render inappropriate affordances acquired by the learners that is not functional. Such a case for establishing representative learning design is clearly supported by motor learning investigations outside of school settings (see Pinder et al., 2011). Recently, Tan et al. (2012) also discussed appropriate pedagogical principles that can underpin a nonlinear pedagogical approach. The pedagogical principle of representation ensures that the information-movement coupling of the structured game or practice is relevant and representative of the actual game. Using ideas of task simplification rather than task decomposition can further enhance representation (Davids et al. 2008). From a practitioner point of view, modifying games will encourage learners to access key perceptual information available in the performance context and couple them with appropriate actions. Tan et al. (2012) further stressed that the aim of representation is for learners to experience opportunities for developing tactical awareness, making appropriate decisions, and practicing skills in manageable practice environments. This is clearly evident of a sound representative learning design where situated learning is encouraged.

Creating an Intrinsically Motivating Learning Environment

It is paramount that practitioners provide a learning environment that is intrinsically motivating for learners. Chow et al. (2013) highlighted how a nonlinear pedagogical approach can provide such a context where learners are motivated to learn. Underpin by self-determination theory (see Deci & Ryan, 2000), it has been suggested that a key requirement for a curriculum that aims to educate children through the medium of physical activity and sport is to ensure that chosen activities and pedagogical approaches support learners' attempts to always act to satisfy the basic psychological needs of autonomy, competence and relatedness (see Chow et al., 2013). Certainly, the key question is how to create such an intrinsically motivating learning environment within the framework of nonlinear pedagogy?

Chow et al. (2013) also stressed that teaching methods should facilitate opportunities to pursue autonomy, competence and relatedness which will result in intrinsic motivated behaviors such as effort, persistence and problem solving with respect to goal tasks. By manipulating suitable and relevant task constraints such as rules, equipment and task goals, practitioners can design learning activities situated in game settings that cater to individual learning needs. When these individual differences are catered for, there will be greater opportunities for the learners to fulfill their psychological needs. Working in *smaller groups* (e.g., small-sided games of not more than 4v4), presenting problem solving opportunities through appropriate *questioning* and using learning activities that support *task simplification* rather than task decomposition can allow learners to explore and acquire individual specific movement solutions. With such a focus on learner-centeredness, a sense of autonomy (e.g., through making decisions on their own), competence (e.g., through being successful at meeting task goals from modified activities) and relatedness (e.g., though opportunities for interaction among peers in small-sided games) can be attained more readily (also see Renshaw, Oldham, & Bawden, 2012 for a discussion on how nonlinear pedagogy underpins intrinsic motivation).

Conclusion

It must be stressed that it is not the aim of this paper to provide all the information related to nonlinear pedagogy since this would go beyond the required limit for this paper. Nevertheless, the clear message from this paper shows that the understanding and acceptance of a nonlinear approach to pedagogy and coaching is catching on. However, the actual delivery of such an approach needs further work to inform practitioners on how it can be realistically undertaken in a coaching and PE context. It must be recognized that nonlinear pedagogy does not advocate a fixed ‘progression’ on how teaching and learning should occur. It is unlikely that a radical paradigm shift will occur in practical settings just yet. More likely, at the present moment, teachers may recognise elements of a nonlinear pedagogy approach (e.g., exploration through variability, emphasis on creativity, constraints adaptation and a focus on the individual) within existing methods and harness them for effective teaching. As with TGfU and other PE pedagogies, the evolution of Nonlinear Pedagogy is dependent on its uptake in schools. The way forward is therefore not easy but nevertheless, we have embarked on this journey to explore the richness that the understanding of nonlinearity can offer in helping our children learn movement skills more effectively and meaningfully.

Nevertheless, this paper serves as a useful starting point in attempting to understand nonlinear learning for sports scientists, coaches and teachers. It provides the sign posts to relevant discussion and content with regards to nonlinear learning and gives an overview of the features of a Nonlinear Pedagogical approach. While there have been numerous papers published on the topic of complexity thinking and nonlinear pedagogy pertaining to skill acquisition, this paper helps to consolidate and provide a succinct discussion of nonlinear learning. Valuable insights of the evidences from motor learning literature and also the advancement in our understanding of the complex and dynamic processes inherent in learning movement skills are shared in this paper. Challenges on the impact and adoption of nonlinear pedagogy were also discussed and this is particularly insightful as it highlights the difficulties that practitioners in particular, grapple with in trying to implement a nonlinear pedagogical approach. Implications for researchers and practitioners were also discussed to provide researchers and practitioners on some ideas to implement empirical investigations as well as practices from this pedagogical approach.

References

Allison., S., & Thorpe, R. (1997). A comparison of the effectiveness of two approaches to teaching games within physical education. A skills approach versus a games for understanding approach. *British Journal of Physical Education*, *28*(3), 9-13.

Barab, S. A., Cherkes-Julkowski, M., Swenson, R., Garrett, S., Shaw, R. E., & Young, M. (1999). Principles of self-organization: Learning as participation in autocatakinetic systems. *The Journal of the Learning Sciences, 8*(3&4), 349-390.

Barris, S. (2008). Automatic tracking and the analysis of human movement. *International Journal of Performance Analysis in Sport, 8*(2), 102-113.

Barris, S., & Button, C. (2008). A review of vision-based motion analysis in sport. *Sports Medicine, 38*(12), 1025-1043.

Barris, S., Farrow, D., & Davids, K. (in press). Do the kinematics of a baulked take-off in springboard diving differ from a completed dive? *Journal of Sports Sciences*.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied*, *8*(1), 6-16.

Bernstein, N. A. (1967). *The co-ordination and regulation of movements*. Oxford: Pergamon Press.

Blomqvist, M., Luhtanen, P., & Laakso, L. (2001). Comparison of Two Types of Instruction in Badminton. *European Journal of Physical Education, 6*(2), 139 - 155.

Bourbousson, J., Seve, C., & McGarry, T. (2010). Space-time coordination dynamics in basketball: Part 1. Intra- and inter-couplings among player dyads. *Journal of Sports Science, 28*(3), 339-347.

Chappell, G. (2004). *Cricket: The making of champions*. Melbourne: Lothian Books.

Chow, J. Y. (2010). Insights from an Emerging Theoretical Perspective in Motor Learning for Physical Education. In M. Chia & J. Chiang (Eds.). *Sport Science in the east: Reflections, issues and emergent solutions* (pp. 59-78). World Scientific Publishers.

Chow, J. Y., & Atencio, M. (2012). Complex and nonlinear pedagogy and the implications for physical education. *Sport, Education and Society*, 1-21.

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araújo, D. (2006). Nonlinear pedagogy: A constraints-led framework to understand emergence of game play and skills. *Nonlinear Dynamics, Psychology and Life Sciences*, *10*(1), 71-104.

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araújo, D. (2007). The role of nonlinear pedagogy in physical education. *Review of Educational Research, 77,* 251-278.

Chow, J. Y., Davids, K., Button, C., Rein, R., Hristovski, R., & Koh, M. (2009). Dynamics of multi-articular coordination in neurobiological systems. *Nonlinear Dynamics, Psychology and Life Sciences*, *13*(1), 27-52.

Chow, J. Y., Davids, K., Hristovski, R., Araújo, D., & Passos, P. (2011). Nonlinear Pedagogy: Learning design for self-organizing neurobiological systems. *New Ideas in Psychology, 29*, 189-200.

Chow, J. Y., Renshaw, I., Button, C., Davids, K., & Tan, C. W. K. (2013). Effective Learning Design for the Individual: A Nonlinear Pedagogical Approach in Physical Education. In

A. Ovens, T. Hopper & J. Butler (Eds.). *Complexity thinking in physical education: Reframing curriculum, pedagogy and research* (pp. 121-134). London: Routledge.

Crossman, E. R. F.W. (1959). A theory of the acquisition of speed-skill. *Ergonomics, 2*, 153-66.

Davids, K., Bennett, S., & Newell, K. M. (2006). *Movement system variability*. Champaign, IL: Human Kinetics.

Davids, K., Button, C., & Bennett, S. J. (2008). *Coordination and control of movement in sport: An ecological approach.* Champaign, IL: Human Kinetics.

Davids, K., Chow, J. Y., & Shuttleworth, R. (2005). A constraints-based framework for nonlinear pedagogy in physical education. *Journal of Physical Education New Zealand, 38*, 17-29.

Davis, B., & Sumara, D. (2006). *Complexity and education: Inquires into learning, teaching and research.* London: Lawrence Erlbaum.

Deci, E. L., & Ryan, R. M. (2000). The ‘what’ and ‘why’ of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry, 11*(4), 227-268.

Dunwoody, P. T. (2007). The neglect of the environment by cognitive psychology. *Journal of Theoretical and Philosophical Psychology, 26*, 139–153.

Fajan, B. R., Riley, M. A., & Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*(1), 79-107.

Farrow, D., & Reid, M. (2010). The effect of equipment scaling on the skill acquisition of beginning tennis players. *Journal of Sports Sciences, 28*(7), 723 - 732.

Gibson, J. J. (1986). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Gough, N. (2010). Lost children and anxious adults: Responding to complexity in Australian education and society. In D. Osberg & G. Biesta (Eds.), *Complexity theory and the politics of education* (pp. 39-55). Rotterdam: Sense Publishers.

Greenwood, D., Davids, K., & Renshaw, I. (2012). How elite coaches' experiential knowledge might enhance empirical research on sport performance. *International Journal of Sports Science & Coaching*, *7*(2), 411-422.

Gray, S., & Sproule, J. (2011), Developing pupils' performance in team invasion games. *Physical Education and Sport Pedagogy, 16*(1), 15-32.

Harrison, J. M., Preece, L. A., Blakemore, C. L., Richards, R. P., Wilkinson, C., & Fellingham, G. W. (1999). Effects of two instructional models - skill teaching and mastery learning - on skill development, knowledge, self-efficacy, and game play in volleyball. *Journal of Teaching in Physical Education*, *19*(1), 34-57.

Hmelo-Silver, C. E., Marathe, S., & Liu, L. (2007). Fish swim, rock sit, and lungs breathe: Expert-novice understanding of complex systems. *The Journal of the Learning Sciences, 16*(3), 307-331.

Hristovski, R., Davids, K., Passos, P., & Araújo, D. (2012). Sport performance as a domain of creative problem solving for self-organizing performer-environment systems. *The Open Sports Sciences Journal, 5*(Suppl 1-M4), 26-35.

Jess, M., Atencio, M., & Thorburn, M. (2011). Complexity theory: Supporting curriculum and pedagogy developments in Scottish physical education. *Sport, Education and Society*, *16*, 179-199.

Kapur, M. (2012). Productive failure in learning the concept of variance. *Instructional Science,* doi 10.1007/s11251-012-9209-6.

Kulikowich, J. M., & Young, M. F. (2001). Locating an Ecological Psychology methodology for situated action. *Journal of the Learning Sciences, 10*(1&2), 165-202.

Lee, A. M. (2003). How the field evolved. In S.J. Silverman & C.D. Ennis (Eds.), *Student learning in physical education: Applying research to enhance instruction* (pp. 9-25). Champaign, IL: Human Kinetics.

Liu, Y-T, Mayer-Kress, G., Newell, K. M. (2003). Beyond curve fitting: a dynamical systems account of exponential learning in a discrete positioning task. *Journal of Motor Behavior, 35*, 197-207.

Liao, C.-M., & Masters, R. S. W. (2001). Analogy learning: A means to implicit motor learning. *Journal of Sports Sciences, 19*, 307-319.

Metzler, M. (2011). *Instructional models for physical education (3rd ed.)*. Scottsdale, AZ: Holcomb Hathaway.

Newell, K. M. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor development in children. Aspects of coordination and control* (pp. 341-360). Dordrecht, Netherlands: Martinus Nijhoff.

Newell, K. M., Liu, Y-T., & Mayer-Kress, G. (2008). Landscapes beyond the HKB Model. In A. Fuchs & V. K. Jirsa (Eds.), *Coordination: Neural, behavioral and social dynamics.* Berlin: Springer Verlag.

Newell, K. M., & Liu, Y-T. (2012). Functions of learning and the acquisition of motor skills (with reference to sport). *The Open Sports Sciences Journal, 5*(Suppl 1-M3), 17-25.

Ovens, A., Hopper, T., & Butler, J. (2013). *Complexity thinking in physical education*. London: Routledge.

Peh, Y.-C. S., Chow, J. Y., & Davids, K. (2011). Focus of attention and its impact on movement behavior. *Journal of Science and Medicine in Sport*, *14*, 70-78.

Pinder, R. A., Davids, K., & Renshaw, I. (in press). Metastability and emergent performance of dynamic interceptive actions. *Journal of Science and Medicine in Sport*.

Port, R. F., & van Gelder, T. (1995). *Mind as motion: Explorations in the dynamics of cognition*. Cambridge, MA: MIT Press.

Renshaw, I. (2010). Building the foundation. In I. Renshaw K. Davids & G. J. P. Savelsbergh (Eds.). *Motor learning in practice: A constraints-led approach* (pp. 33-44). London: Routledge.

Renshaw, I., Chow, J. Y., Davids, K., & Hammond, J. (2010). A constraints-led perspective to understanding skill acquisition and game play: A basis for integration of motor learning theory and physical education praxis? *Physical Education and Sport Pedagogy*, 1-21.

Renshaw, I., Davids, K., & Savelsbergh, G. J. P. (2010). *Motor learning in practice. A constraints-led approach.* London: Routledge.

Renshaw, I., Davids, K., Shuttleworth, R., & Chow, J. Y. (2009). Insights from ecological psychology and dynamical systems theory can underpin a philosophy of coaching. *International Journal of Sport Psychology, 40*, 580-602.

Renshaw, I., Oldham, A. R., & Bawden, M. (2012). Nonlinear pedagogy underpins intrinsic motivation in sports coaching. *The Open Sports Sciences Journal, 5*(Suppl 1-M10), 88-99.

Richard, J., & Wallian, N. (2005). Emphasizing student engagement in the construction of game performance. In L. Griffin & J. Butler (Eds.). *Teaching games for understanding: Theory, research and practice* (pp. 19-32). Champaign, IL: Human Kinetics.

Rovegno, I., Nevett, M., Brock, S., & Babiarz, M. (2001). Teaching and learning basic invasion-game tactics in 4th grade: a descriptive study from situated and constraints theoretical perspectives. *Journal of Teaching in Physical Education 20,* 370-88.

Schöllhorn, W. I., Hegen, P., & Davids, K. (2012). The nonlinear nature of learning- A Differential Learning approach. *The Open Sports Sciences Journal, 5*(Suppl 1-M11), 100-112.

Schöllhorn, W. I., Mayer-Kress, G. M., Newell, K. M., & Michelbrink, M. (2009). Time scales of adaptive behavior and motor learning in the presence of stochastic perturbations. *Human Movement Science, 28*(3), 319-333.

Seifert, L., & Davids, K. (2012). Intentions, perceptions and actions constrain functional intra- and inter individual variability in the acquisition of expertise in individual sports. *The Open Sports Sciences Journal, 5*(Suppl 1-M8), 68-75.

Seifert, L., Wattebled, L., L'Hermette, M., Hérault, R. (2011). Inter-limb coordination variability in ice climbers of different skill level. *Education, Physical Training, Sport, 1,* 63-8.

Snoddy, G. S. (1926). Learning and stability. *Journal of Applied Psychology, 10*, 1-36.

Tan, C. W. K., Chow, J. Y., & Davids, K. (2012). "How does TGfU work?": Examining the relationship between learning design in TGfU and a nonlinear pedagogy. *Physical Education and Sport Pedagogy*, *17*(4), 331-348.

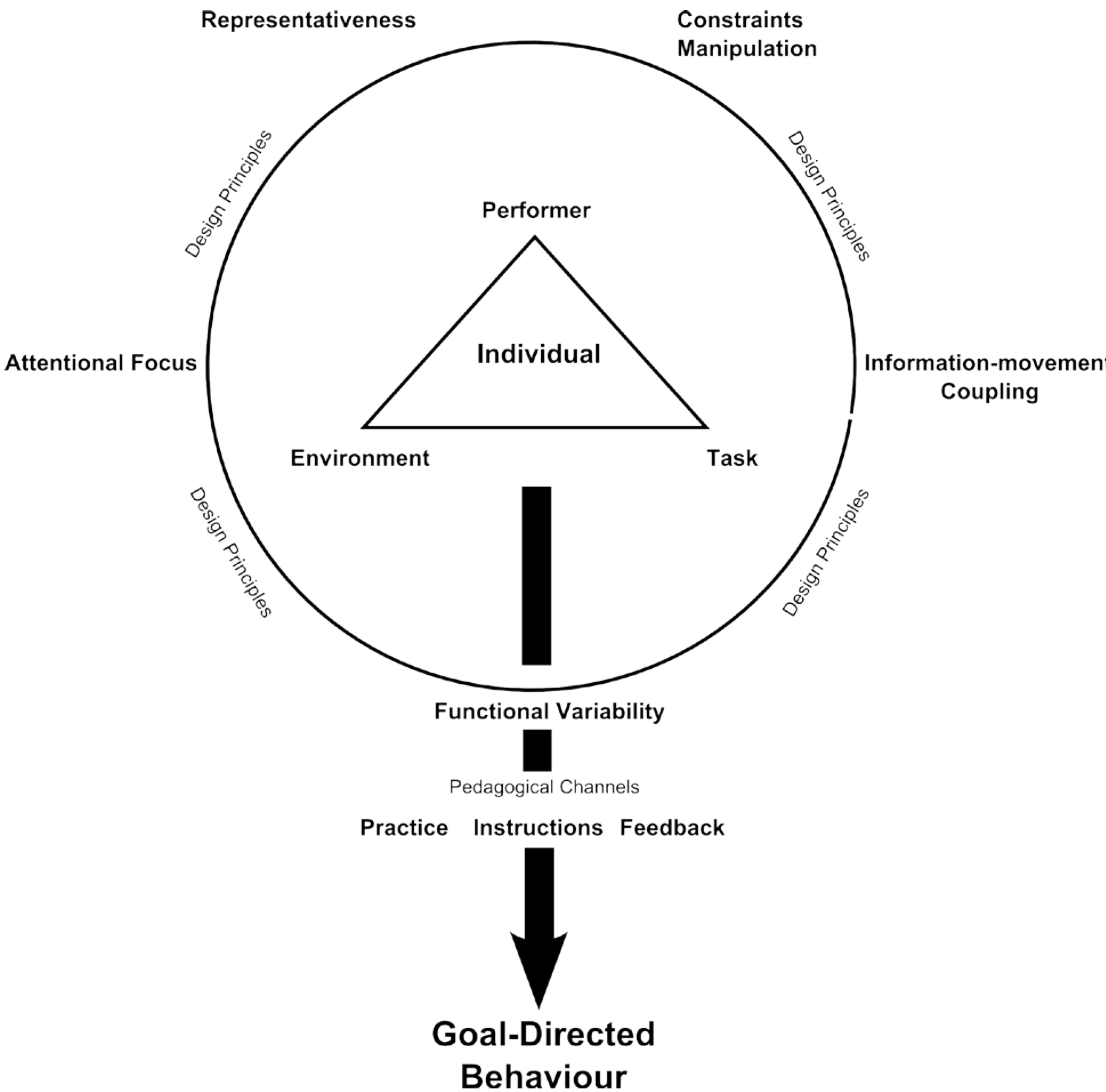
Thorpe, R., & Bunker, D. (1989). A Changing Focus in Games Teaching. In L. Almond (Ed.). *The place of physical education in schools* (pp. 42-71). London: Kogan Page.

Tinning, R., & Rossi, A. (2013). Thinking about complexity thinking for physical education. In A. Ovens, T. Hopper & J. Butler (Eds.). *Complexity thinking in physical education: Reframing curriculum, pedagogy and research* (pp. 194-208). London: Routledge.

Turvey, M. T., & Shaw, R. (1995). Toward an ecological physics and a physical psychology. In R. L. Solso & D. W. Massaro (Eds.), *The science of the mind: 2001 and beyond* (pp. 144-169). New York: Oxford University Press.

Wulf, G. (2007). *Attention and Motor Skill Learning.* Champaign, IL: Human Kinetics.

Figure 1.


Representativeness
Constraints Manipulation
Design Principles
Design Principles
Performer
Individual
Attentional Focus
Information-movement Coupling
Environment
Task
Design Principles
Design Principles
Functional Variability
Pedagogical Channels
Practice
Instructions
Feedback
Goal-Directed Behaviour