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A Dynamical Reconceptualization of Executive-Function Development

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Abstract

Executive function plays a foundational role in everyday behaviors across the life span. The theoretical understanding of executive-function development, however, is still a work in progress. Doebel proposed that executive-function development reflects skills using control in the service of behavior—using mental content such as knowledge and beliefs to guide behavior in a context-specific fashion. This liberating view contrasts with modular views of executive function. This new view resembles some older dynamic-systems concepts that long ago proposed that behavior reflects the assembly of multiple pieces in context. We dig into this resemblance and evaluate what else dynamic-systems theory adds to the understanding of executive-function development. We describe core dynamic-systems concepts and apply them to executive function—as conceptualized by Doebel—and through this lens explain the multilevel nature of goal-directed behavior and how a capacity to behave in a goal-directed behavior during childhood and, finally, address broader theoretical implications of dynamic-systems theory and propose new translational implications for fostering children's capacity to behave in a goal-directed fashion across everyday contexts.

Keywords

cognition, child development, developmental process, dynamic-systems theory, executive function

The study of executive-function development blossomed in the early 2000s. This growth was motivated by several observations indicating that executive function has a foundational role in human development (Carlson et al., 2013). For example, executive function during childhood is associated with school readiness (Mann et al., 2017), academic achievement (Allan et al., 2014; Blair & Razza, 2007), and social-emotional competence (McClelland et al., 2007) and predicts long-term developmental outcomes well into adulthood, such as health, wealth, and involvement in criminal activity (Moffitt et al., 2011). The use of executive function is also tied to cortical activity and development of prefrontal regions of the brain (Buss & Spencer, 2018; Crone et al., 2006; Espinet et al., 2012; Moriguchi & Hiraki, 2009) that have long been viewed as the epicenter of higher-level thought processes (for a discussion, see Teffer & Semendeferi, 2012). Executive function is most often used as an umbrella term to refer to a set of neurocognitive processes-working memory,

inhibitory control, and cognitive flexibility—said to be involved in controlling behavior in a goal-directed fashion (Miyake et al., 2000; Zelazo, 2015). This characterization of executive function has had a powerful influence in shaping how psychologists conceptualize and measure executive function.

Doebel (2020) wrote a liberating piece that casts convincing doubt on the aforementioned three processes as structural components of executive function. Doebel leveled her criticism on four specific points: (a) The evidence that training specific components will improve cognitive functions across domains or contexts is mixed, (b) measures of components in the lab do not consistently correspond with more general or realworld measures of self-regulation (e.g., questionnaires),

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(c) the evidence for a mechanistic link between labbased measures of executive function and developmental outcomes is not yet compelling, and (d) components cannot be purified of contextual and specific task demands. Doebel cautioned against reduction of executive function to separable components, reification of components, and positing a mechanistic connection between these components as measured in lab-based tasks to real-world behaviors.

Doebel (2020) proposed a new view of executive function as the "development of skills in using control in the service of behavior" in which "specific goals activate mental content like relevant knowledge, beliefs, values, norms, interests, and preferences that children acquire with development and that shape how they use control" (p. 945). By this view, children do not have an inhibitory control component that is activated in relevant contexts, such as sitting still in the classroom during story time. Instead, children use whatever information they have to muster up the control to pursue a specific goal in context. Doebel provided a concrete example of a child using control to pursue the goal to avoid hitting a playmate who took a toy by recruiting knowledge of the negative experience of being hit, knowledge of alternative strategies, values not to invoke harm on others, and so on.

Doebel's (2020) view is refreshing. It takes behavior in context seriously-what the child is asked to do and where the child is asked to do so matters-and is inherently relevant to understanding real-world behaviors, such as pursuing the goal to resolve a conflict with a friend, sit still during story time, or solve a math problem. We were struck by the resemblance of some of Doebel's ideas to dynamic-systems concepts. For example, the confluence of multiple factors on cognition and behavior in context is reminiscent of an old idea introduced by Thelen (1992) called soft assembly-children assemble multiple components¹ in the moment to behave within the demands of the context. Most notably, dynamic systems theories of cognitive and behavioral development proposed long ago the notions that cognition and behavior should always be understood in context (e.g., not hitting a playmate vs. resisting a marshmallow) and that there are no cognitive or behavioral components that can be activated and applied across contexts (e.g., inhibitory control; Smith et al., 1999; Thelen & Smith, 1994). One key point of contrast between Doebel's view and the dynamic-systems theory offered herein is the nature of control and goal-directed behavior. In Doebel's view, control is engaged to pursue a goal. The goal activates mental content, which is used to pursue the goal in a specific context; however, in the dynamic systems view, the pursuit of a goal emerges from the relevant mental content and context together. In this

way, goal-directed behavior is built from but, importantly, not reducible to these components.

Soft assembly is one of many general dynamic-systems theory concepts that have been applied to numerous well-known domains in psychology, including motor control, visuospatial cognition, gender identity, and language. The concepts have been applied across developmental periods as well, including infancy, early childhood, adulthood, and late adulthood (e.g., Bhat et al., 2018; Corbetta & Thelen, 1996; Costello & Buss, 2018; Fausto-Sterling, 2012; Harris, 2005; Perone & Simmering, 2019; Samuelson et al., 2009; Schöner & Kelso, 1988; Schutte & Spencer, 2009; Smith et al., 1999; Tas et al., 2020; Thelen et al., 1996, 2001). The goal of our commentary is to dig deeper into what dynamic-systems concepts might contribute to the understanding of executive function-as construed by Doebel (2020)-and its development.

In the subsequent section, we review important dynamic-systems concepts. We introduce these concepts within the framework of motor development in part because they were initially formulated in the motor domain and in part because we believe their introduction to readers unfamiliar with the concepts is most intuitive and transparent in the motor domain. We then discuss how these concepts can be applied to executive function and review how a dynamic-systems process model has been applied to children's performance in lab-based executive function tasks. We close with a discussion of the implications of the view expressed here and insights from the model for helping children improve their capacity to behave in a goal-directed fashion in real-world contexts.

Dynamic-Systems Theory: Core Concepts

In the 1990s, Thelen, Smith, and colleagues introduced a number of core dynamic-systems concepts to the development of cognition and action (Thelen & Smith, 1994; for reviews, see Perone & Simmering, 2017; Smith & Thelen, 2003; Spencer et al., 2006). They construed cognition and behavior as an emergent product of a softly assembled system. Dynamic-systems theory is generalizable because it does not differentiate among the principles governing seemingly distinct phenomena from change in ecosystems to change in societies (Lewis, 2000; for examples, see Waldrop, 1992). For instance, in the study of development, there is no meaningful distinction in the developmental processes involved in learning to walk compared with learning to solve an algebra problem. When infants learn to walk, they assemble multiple components-their leg muscles, core muscles, and capacity to balance their weight against the force of gravity-to exert strength

and take that first step. This moment is a real-time state that is a building block of learning to walk. Likewise, when students learn to factor polynomials, they assemble multiple components—their knowledge of common factors, appropriate step-by-step procedures, and their ability to carry out simpler arithmetic operations—to piece together the set of operations required to solve the math problem. This moment is a real-time state that is a building block of advancing their skill in algebra.

In dynamic-systems theory, these real-time states exist only in the moment. However, because systems are historical, a system tends to recreate previous states. When a system enters a similar state over and over again, it becomes a preferred state. For instance, as an infant learns to walk, he or she begins to walk more frequently than crawl. One might then say the child is now in the walking stage and no longer in the crawling stage of locomotion because walking has become a stable and preferred pattern of organization. Note that the preferred state a system enters is context dependent even an adult will crawl on hands and knees to escape below the smoke of a fire.

The organization of a system is multicausal and happens across multiple, interactive levels. Thelen and Ulrich's (1991) research on the stepping reflex is a concrete example of these concepts (for a discussion, see Spencer et al., 2006). Infants' stepping behavior comes and goes depending on the context (e.g., in water, upright, lying down) and the strength and weight of their legs. Stepping emerges from the soft assembly of these components in the moment-no single component has causal priority-and the influence of one component is contextualized by the properties of the other components. For instance, the force needed to move the leg of a given weight depends on various contextual factors, such as the direction gravity is pulling relative to the posture of the body, muscle stretch, and cortical activity in motor cortex. The multicausality of softly assembled behaviors enables the child to flexibly adapt to a changing and variable world via simultaneous coordination of processes across levels, including brain, body, and social-emotional processes within the physical elements of the environment.

Dynamic systems theorists have proposed that development reflects the capacity to create and enter an increasing number of possible preferred states (Spencer & Perone, 2008; Spencer & Schöner, 2003; Thelen, 1992; Thelen & Smith, 1994). These preferred states are often referred to as *attractors* and reflect the real-time organization of a system in context, emerging in the moment, leaving a history, and dissipating. We can see the emergence of multiple preferred states for locomotion during the first 2 years of a typical North American infant's life (Adolph et al., 2018). As infants learn to coordinate muscle groups through actions such as rolling, sitting, and pushing or pulling up, they begin to combine these exercised components into other, new organized behaviors such as crawling, creeping, scooting, cruising, walking, or running. This behavioral repertoire reflects what is called an *attractor landscape* of possible preferred states that emerges over development. This landscape is built from the improvement of individual components (i.e., muscle strength) and the self-organization of these components into new behaviors across contexts.

The introduction of dynamical systems to developmental psychology emerged from the study of motor control in early infancy. From this initial work, however, the general principles described in the preceding paragraphs have been applied to other domains of development. In the next section, we examine how these principles can be applied to and extend our understanding of executive-function development as conceptualized by Doebel (2020).

Executive-Function Development as a Dynamic System

The study of executive-function development fits naturally within dynamic-systems theory. Executive function is often conceptualized as enabling humans to behave flexibly and adaptively in a wide array of changing and variable contexts (e.g., Zelazo, 2015). Likewise, dynamic systems organize themselves in the service of adaptive functions, and their behavior grows more complex over developmental time (Lewis, 2000). For instance, a sitting infant will topple over to the prone position and begin rocking back and forth, building up the strength to move his or her limbs and scoot forward. Day in and day out, infants will eventually learn to coordinate their limbs and crawl to a piece of furniture, reach up, grasp, pull themselves up, and muster the strength and balance to take a step. These early goal-directed behaviors ultimately develop into the more complex behaviors we observe when a child races after a soccer ball in pursuit of scoring a goal to win the game.

What dynamic-systems theory provides that extends the framework outlined by Doebel (2020) is a way to think about how development happens in executive function. For example, how does a child develop the ability to sit still and listen during story time in the context of distractions from the social and physical environments? Within Doebel's framework, a child sitting still during story time is construed as using control to pursue a goal to listen to a story by using knowledge about story-time routines, desire to hear a story, and so on. A key question, however, is what control is. In Doebel's view, control is construed as an active force driving goal-directed behavior. In this way, control is used by a volitional agent. In dynamic-systems theory, goal-directed behavior in the moment reflects the assembly of multiple components and might involve a desire to hear a story, prior knowledge of story time, processes related to attention, recognition, recollection, and motor control. In this way, control is not used to drive goal-directed behavior; rather, goal-directed behavior emerges as a property of a softly assembled, multicomponent system (Buss & Spencer, 2014). In this view, volition and agency are not separate from the forces that conspire to structure or organize behavior. For example, the ability of the child to sit still during story time might involve recognition of the value of hearing a story, complying with rules, and so on, and the behavior, in turn, emerges in the moment over other possible behaviors. Systems are multilevel, and so sitting still is assembled through neural activity, muscle activity, emotion regulatory processes, motivational processes, and so on, which come together with cognitive processes in the moment. The shared developmental history of these components biases the system to reenter the same state again in the future, ultimately becoming a preferred state of the system over time. This child might be described as "having good selfcontrol," but such "self-control" within dynamic-systems theory is the ability to reliably assemble the pieces needed to behave appropriately in a given context, especially in the face of conflict. Although one might commonly refer to this ability as "control," it is not a separable process in dynamic-systems theory.

The aforementioned example describes only how a child develops the capacity to exhibit control to sit still during story time. However, children need to develop the capacity to exhibit control as they pursue a vast array of goals across many contexts. On a daily basis, a child may need to sit still during story time, resolve conflicts with friends, wait to cross a busy street, maintain composure at the dinner table, wait patiently in the lunch line, transition to the classroom from recess, and much more. What enables a child to develop such a complex repertoire of skills? We contend children's goal-directed behaviors reflect the real-time organization of a multicomponent, multilevel system such that physiological, cognitive, emotional, and motor processes come together with the social and physical forces in the environment in the moment to drive goaldirected behavior. Each time children pursue a goal, a history of the underlying organization of the system is left behind that, in turn, biases children to recreate those states in the future, ultimately enabling them to more reliably enter those states in the future. Over time, two things happen. First, children are more likely to behave in a similar way across contexts, such as sitting still during story time, maintaining composure at the dinner table, waiting patiently in line, and so on, each and every day. Second, children acquire more and more possible states that provide them more components to softly assemble to create new states, such as successfully withholding a response the first time they play Simon Says, or behaviors reflecting more complex processes, such as resolving a conflict with a friend on the playground. This allows the very flexibility to adapt to a variable and changing world to act skillfully.

The capacity to create new behaviors and to flexibly adapt to conflict arising in the current context is an important property of development and of a dynamic system. When children play Simon Says for the first time, for instance, they assemble many components used to create other goal-directed behaviors, such as attention, language, movement, familiarity of leadfollow games, and so forth. The use of these components to assemble more and more behaviors over time makes them more likely to be assembled to create a new behavior within the support of the environment (e.g., instructions). This idea points to the important role of variability within and across individuals because experience assembling components across contexts creates and establishes the building blocks of increasingly more complex goal-directed behaviors in development (van Geert & van Dijk, 2002). Identifying components and specifying how they work together, however, is not trivial. We illustrate one approach to doing so in the subsequent section.

Empirical illustration

Executive function in children has, to date, most often been studied in the lab. Dynamic-systems theory has been applied to a canonical lab-based probe of executive function in young children called the *dimensional change card-sort* task (DCCS; Zelazo, 2006). In this section, we review this application, and in the concluding section, we extend the insights garnered from this application to fostering goal-directed behavior in realworld settings.

The DCCS task is an adaptation of the Wisconsin card-sort task often used as a neuropsychological assessment of prefrontal function (Milner, 1963). In the DCCS task, children are situated in front of target cards depicting bidimensional objects (e.g., blue star and red circle). They are presented with a set of response cards that match each target card by one dimension (e.g., blue circle). During the preswitch phase, children are told a rule (e.g., sort by shape), and during the postswitch phase, children are told a new rule (e.g., sort by color). Three-year-old children continue to sort by the preswitch rule throughout the postswitch phase even when regularly reminded of the postswitch rule. Five-year-old children, by contrast, readily switch to sort by the postswitch rule. The DCCS task is one of only a few tasks in which children's performance qualitatively shifts over a short period of development and also to have known ties to prefrontal function in children (Buss & Spencer, 2018; Espinet et al., 2012; Moriguchi & Hiraki, 2009). Moreover, the DCCS task captures a developing capacity to flexibly adapt across contextsthe preswitch and postswitch phases-to behave in a goal-directed fashion. Not surprisingly, then, the DCCS task has been the focal point of several theories explaining developmental change in children's performance, including improved capacity to reflect on the rules (Zelazo, 2004), attentional inertia (Kirkham et al., 2003), redescription of objects (Kloo & Perner, 2005), and capacity for working memory to overcome habits (Morton & Munakata, 2002). Doebel (2020) proposed successful switching in the DCCS task may be due to conceptual knowledge of shape and color, which she noted are not merely idiosyncratic features of the task. Doebel proposed that acquiring knowledge about such dimensions might make children more aware of various aspects of the task at hand. Indeed, several studies testing novel predictions of a dynamic-systems model of children's performance in the DCCS task have shown just this (Perone et al., 2015, 2019).

The use of formal dynamic-systems models has provided the opportunity to specify the components of multiple interactive systems and study developmental processes. Buss and Spencer (2014) presented a neural network that formally implements the core dynamicsystems concepts described in the preceding sections to simulate the neurocognitive and behavioral dynamics involved in performing the DCCS task, including experiential, contextual, and developmental influences on performance (Buss & Kerr-German, 2019; Buss & Nikam, 2020; Buss & Spencer, 2014, 2018; Perone et al., 2015, 2019). Within the model, performing the DCCS task reflects the dynamics of two interactive systems: an object-representation system that binds visual features sampled from multiple dimensions together at spatial locations and a *label-learning system* that associates labels such as *shape* with the visual features corresponding to these labels. Children's use of rules to guide their sorting behavior in a goal-directed fashion involves using labels, such as shape to sort a card depicting a multidimensional object (e.g., red star) by a particular dimension (e.g., shape) to a spatial location (e.g., left). Each sorting decision is carried forward across trials. The history of repeatedly sorting by one dimension strongly influences young children's sorting behavior, biasing them to continue to sort by the preswitch dimension in the postswitch phase. Note that real-world experience using labels and remembering

objects over dimensions strengthens the neural connectivity governing the object representation and labellearning systems. This, in turn, enables the model to adapt to the postswitch phase by creating a new preferred stated that is less influenced by prior history from the preswitch phase and more by the immediate rule context provided in the task environment (for a discussion, see Perone et al., 2019). This occurs via coupling of labels and visual features, which allows the model to prioritize or enhance processing of features or dimensions to behave in a goal-directed fashion within the current sorting context.

Goal-directed behavior in the model is softly assembled from the dynamics of neural representations-a rule to sort by color, for instance, involves preferentially recruiting neurons tuned to processing of color information. The model simulates sorting behaviors that researchers often attribute to the processes of working memory (holding a rule in mind), inhibitory control (selectively processing one dimension while ignoring another), and cognitive flexibility (switching rules). Critically, in dynamic-systems theory, there are no "modules" that correspond to these constructs. Rather, one set of neural processes governing the object representation and label-learning systems self-organizes within the demands of the specific task and developmental context to behave in a goal-directed fashion (for a detailed review, see Buss & Spencer, 2014). Note that in the model, label information from a rule to "sort by color" or "sort by shape" provided in the environment is input to a single neuron. This is a simplification of a much more complex reality. Nevertheless, it captures the hypothesized role of rule-related information-in this case a label-in the interactive dynamics of a multicomponent system giving rise to goal-directed behavior.

The soft-assembly perspective provides the opportunity to delineate many influences on children's sorting behavior in the DCCS task. This is because alterations to one component of the system alters the organization of the entire system, whether it be the task space, history of sorting cards, neural connectivity, or prior experience. This concept has important implications for improving children's goal-directed behavior in labbased and real-world settings alike. We briefly illustrate four examples here.

First, the visual structure provided by the task can alter 3-year-old children's sorting behavior: The absence of target cards makes switching easier for 3-year-old children (Towse et al., 2000). This happens in the model because the absence of target cards reduces the saliency of the preswitch dimension during the postswitch phase.

Second, the history of decisions in the task can alter performance: Using no-conflict test cards (e.g., sorting a blue star to a blue star and a red circle to a red circle during the preswitch phase) makes switching easier for 3-year-old children because the features that are relevant for the postswitch phase are sorted to the same location throughout the preswitch and postswitch phases (Buss & Spencer, 2014). This happens because memory traces accumulate during the preswitch phase that strengthen the representation of the postswitch dimension.

Third, providing children experience with color and shape dimensions outside of the DCCS task enabled them to switch rules using different colors and shapes in the DCCS task (Perone et al., 2015, 2019). This happens because experience over dimensions strengthens the neural connectivity involved in creating a new attractor state to use the rules specifying the dimension prior experience was provided with.

Fourth, regarding the label component of the model, Buss and Nikam (2020) tested how children's history with labels affects the ability to use labels to perform the DCCS task. The CHILDES database shows that children's linguistic environment during the first 3 years of life provides much higher exposure to the label color than to the label shape. They administered the DCCS task to 4-year-old children, who are normally successful in the task, a version of the task that used only the labels shape and color rather than features such as blue and star to instruct sorting. With this manipulation, 4-year-old children failed at a significantly higher rate when instructed only with the label shape during the postswitch phase. Within the dynamic-systems model, this observation indicates children's experience with color strengthens the connections between the color in the label component and neural populations tuned to colors in the object representation component before shape in development. This, in turn, enables the model to effectively use a rule to sort by color, but not shape, during the postswitch phase.

The dynamic-systems model has been especially useful in specifying how a brain-based, multicomponent system organizes itself to use rules to guide behavior in the lab. It has shed new light on contextual, experiential, and developmental influences on goal-directed behaviors. It has also brought to light important conceptual distinctions with other theoretical perspectives related to the DCCS task and top-down control more generally. For instance, in Doebel's (2020) view, goals activate knowledge, desires, beliefs, and so on, which, in turn, help children effectively pursue their goal. In our view, goal-related or top-down information (e.g., a rule to sort by shape) and knowledge (e.g., learning about a feature dimension) reciprocally interact to give rise to the goal-directed behavior in an emergent fashion. Other forces play an important role, too. For Perone et al.

and behavior influence children's decisions in the moment. This might include the influence of spontaneously generated correct sorting decisions on prior trials that, in turn, lead a child to continue to sort correctly on subsequent trials (Schöner & Dineva, 2007) or learning about feature dimensions that help guide attention to relevant rule-related cues in the task space (Perone et al., 2015, 2019). Any one of many forces can tip the scale toward or away from effective goal-directed behavior in the moment. The observation that children know and can restate a rule yet fail to use it to guide their behavioral decisions in the DCCS task is good evidence that top-down information is not the only force needed to drive goal-directed behavior (Buss & Spencer, 2012; Munakata & Yerys, 2001; Zelazo et al., 1996).

The emergentist view of goal-directed behavior offered here is not merely semantically distinct or merely a redescription of theoretical views espousing high-level thought processes at a lower level of analysis (Spencer et al., 2011). Consider a seminal theory of developmental change in children's performance in the DCCS task, the cognitive control and complexity theory (Bunge & Zelazo, 2006; Zelazo, 2015; Zelazo & Frye, 1998). The theory posits that children's improving capacity to reflect on and navigate multiple hierarchical rule structures (e.g., "if color game, and if blue, then sort here, but if shape game, and if star, then sort there) enables them to succeed in the DCCS task. Through reflection and iterative reprocessing of information, children can construct increasingly complex rule structures. In our view, by contrast, such rule use exists only in a multilevel, multicausal system. Rule use in the DCCS task can be described as hierarchical, but it emerges from children's use of rule-related cues from an experimenter, target cards at left and right locations, experience with specific feature dimensions, history sorting cards in the task, and so on. The developmental state of the child plays a key role as well. Dynamicsystems neural-network models have shown that the capacity to simultaneously maintain multiple pieces of information and navigate remembered information across neural population improves with age, which likely is a key piece of using increasingly more complex rule structures (for a discussion, see Buss & Spencer, 2014; also see Spencer, Perone, & Johnson, 2009).

The idea that top-down control drives goal-directed behavior does not exist in a systems perspective because there is only emergence. Top-down information is viewed as one component of a multicomponent, multilevel system that contributes to goal-directed behavior but does not play a privileged role. This contrasts with the commonsense notion or subjective feeling of intentional control as a prior state of mind from which goal-directed behavior follows. So, then, where does this sense of control come from? Top-down information, such as rules, goals, or behavioral expectations, can be provided by environmental cues (e.g., stated rules), elicited through bottom-up cues (e.g., a physiological sensation of anxiety), or emerge as possible routes of action when confronted by environmental constraints (e.g., the familiar road home is blocked). This information, in turn, becomes part of a system driving goal-directed behavior. Consider a concrete example. When a student is said to be pursuing a goal to perform well in a course, for us, the goal may be elicited by external forces (e.g., awareness the student must pass the course to graduate) or emerge via internal forces (e.g., the student spontaneously listens to the instructor's message, is captivated by content, and desires to know more). The goal-related information becomes one of many factors to influence its pursuit, such as moving away from distracting peers in the back of the room, placing distracting items out of sight, taking written notes, sitting in a comfortable chair, and so on. We contend that such a perspective has important implications for how one might approach helping children behave in a goal-directed fashion in real-world settings, which we discuss next.

Real-World Implications and Concluding Remarks

Behaving in a goal-directed fashion is important in almost every aspect of daily life across the life span. One reason Doebel's (2020) view of executive function is valuable is because it has clear translational implications to improve children's ability to engage in goaldirected behaviors in the ordinary real-world contexts in which children think and behave. As she implied, training interventions are typically built on the assumption that a capacity, such as working memory or inhibitory control, can be improved in one context (often a game-like lab task) and then applied in another context (e.g., schoolwork). We now know training of this sort is ineffective for far transfer (e.g., Diamond & Ling, 2016; Kassai et al., 2019; Melby-Lervåg et al., 2016), although other types of interventions targeting executive function have been used and may be more effective (for discussion and important limitations, see Diamond & Ling, 2016). Doebel viewed executive function as the skill to use control in the service of behavior. Thus, she provided guidance on how to approach interventions that focus on goals and related beliefs, norms, and knowledge.

For example, suppose a preschool teacher would like students in the classroom to not put their fingers in their mouth to avoid getting sick. From the three-component view of executive function, training working memory and inhibitory control processes should help children remember the rule to not touch their face and resist the urge to do so. From Doebel's view, by contrast, a more effective approach would be to help children set a goal to not get sick, discuss the value of being healthy, and build their knowledge about how germs can be transmitted by putting fingers in their mouths. From the dynamic-systems perspective, goal-directed behavior is inherently multicausal and depends on processes happening at multiple levels (e.g., brain, behavior, socialemotional). We close with a discussion of how insights about the nature of using goal-related information in the dynamic-systems model described in the preceding section and concepts expressed in this commentary more generally can be used to guide the approach to fostering goal-directed behavior in children. As we highlight, there are many practical implications of this approach that are distinct from those based on Doebel's view.

One insight from the dynamic-systems model of children's rule use proposed by Buss and Spencer (2014) is that goals link cues and contextual information in situations when those goals are relevant. For example, the rule (e.g., sort by color) relates to specific features (e.g., blue) and actions (e.g., sort to the right) in a card-sorting context (e.g., when situated in front of two target cards). The connections linking cues to contextual information are strengthened through use. In practice, helping children behave in a goal-directed fashion should focus on helping them connect goals to cues and provide supporting contextual information. If the target goal-directed behavior is for a child to sit quietly during story time, for example, the goal to sit quietly should be linked to context information, such as gathering for story time, and cues, such as the physical act of sitting down or the teacher opening the book. The links between goals, cues, and contextual information are strengthened through use and make the target behavior more likely to be repeated.

A central tenet of dynamic-systems theory is that behavior is multicausal and multilevel, and so, goaldirected behavior in the here and now is also inherently multicausal and multilevel. Goal pursuit reflects the assembly of motor movements (e.g., limbs, muscles, eye movements), physiological processes (e.g., autonomic and central nervous system), physical environment (e.g., classroom, playground), social-emotional processes (e.g., trusting relationship), and more. The translational implication is there are many routes to help children behave in a goal-directed fashion. Helping a child achieve the goal of sitting quietly to hear a story among his or her peers might be fostered by, for instance, communication with regard to the goal from someone the child has built a trusting relationship with, the alignment of story-time seats in the classroom, separation of quiet and playtime physical contexts, brief mindfulness meditation to lower arousal, signage linking cues to goals, and so on. These are very different methods, but they target distinct pieces of a multicomponent system working together to pursue a goal in the here and now.

Often, the overarching goal of parents, interventions, or early childhood programming is not to help a child pursue one goal in the here and now but to help children develop the capacity to behave in a goal-directed fashion in the many everyday contexts in which this skill is needed. A child's capacity to exhibit goal-directed behavior across a wide array of contexts reflects the development of many possible preferred states, or the attractor landscape. Helping children develop the capacity to act skillfully across a wide array of contexts, then, requires helping children build an attractor landscape by building links between goals (e.g., wait patiently in line, talk with friends, cross road safely) with specific cues (e.g., lunchroom line, lunch table, crosswalk) and contexts (e.g., front of lunchroom, seating area, walking home after school). Note that these real-time behaviors are real-time states that become preferred states with repeated reentry. Put simply, children need to be invited to engage in many different goal-directed behaviors that will, in turn, enable them to more reliably exhibit those goal-directed behaviors as well as pull from their growing experience to engage in new goal-directed behaviors.

Despite best efforts, inevitably some children will struggle to behave in a goal-directed fashion in realworld settings, such as a classroom, in which tailoring strategies to individual children is not practical. The scenario most likely to be successful in helping all children behave in a goal-directed fashion is to enlist multiple strategies and do so uniformly across all children. This is a direct implication of the view that goaldirected behavior emerges from multiple, interactive components, none having causal priority. This means that any given strategy may tip the scales toward goaldirected behavior for any given child (for related discussion, see Kizilcec et al., 2020). One distinct implication of systems is the emphasis on nonobvious influences on behavior and development (Spencer, Blumberg, et al., 2009). It is known that attention and executive function are influenced by many factors, such as nutrition, sleep, family dynamics, and classroom decorations (Cohen et al., 2016; Fisher et al., 2014; Friedman et al., 2009; Obradović et al., 2019). In the view expressed herein, these are not peripheral influences on cognition and behavior. These are part of the system driving goal-directed behavior. Just as the placement of stimuli in the task space can alter the goal-directed behavior of infants and children (Buss & Spencer, 2014; Smith et al., 1999), having a box of sharpened pencils on hand might eliminate the nagging distraction for a given child and enable that child to maintain focus during creative-writing time. We acknowledge that identifying nonobvious factors is a nontrivial endeavor. However, the view nonobvious factors are important, and the pursuit to identify them is a direct implication of systems theories that may prove useful in fostering goal-directed behavior in realworld settings.

One critique of dynamic-systems theory is "it explains everything" or "everything matters" and is therefore not a falsifiable and productive theory (e.g., Braisby et al., 1998). It is true that the theory is based on a set of general principles that can and have been applied in many sciences and domains (Lewis, 2000; Perone & Simmering, 2019; Waldrop, 1992). From our perspective, the generalizability of the concepts makes them quite attractive. However, we contend that the real strength of the concepts lies within specific instantiations of the theory. For example, the application of dynamic-systems concepts has transformed our understanding of motor development (e.g., Spencer et al., 2006; Thelen et al., 1996; Thelen & Ulrich, 1991) and the development of object permanence (e.g., Clearfield et al., 2006; Smith et al., 1999; Thelen et al., 2001) because these applications specified multiple components and how they work together, leading to concrete, novel, testable predictions. When multiple specific explanations of, for instance, word learning and executive function have been thoroughly developed, they may be combined to provide a more complete view of developmental change (Perone & Simmering, 2019; Spencer et al., 2006). Most importantly, these specific applications are falsifiable. For example, the computational model described in the Empirical Illustration section was used to make an a priori prediction about the conditions under which young children's behavior in the DCCS task should be improved, which were not confirmed empirically, requiring revision and further development of the model (Perone et al., 2015). Moreover, here, we proposed specific implications about how to help children behave in a goal-directed fashion that may prove untrue.

In closing, Doebel (2020) wrote a thought-provoking piece that has implications for the conceptualization, measurement, and improvement of executive function. Her recasting of executive function inspired us to look at executive function through the lens of dynamicsystems theory, which, we contend, provides a broader unifying framework for thinking about executive function in the here and now and executive-function development and also has translational implications.

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Note

1. For the purposes of this commentary, it is important to distinguish between the term *component* as it is meant within the context of soft assembly and as it is used in the study of executive function. A component within a softly assembled behavior refers to the more basic parts that interact to produce cognition and behavior. In the three-process view of executive function, *component* is used to refer to cognitive constructs (e.g., working memory, inhibition, or shifting).

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