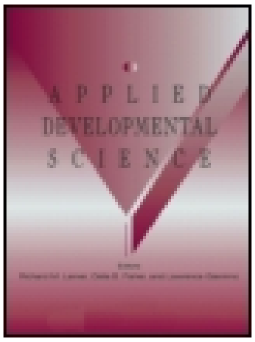

Applied Developmental Science

ISSN: 1088-8691 (Print) 1532-480X (Online) Journal homepage: http://www.tandfonline.com/loi/hads20

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To cite this article: Pamela Cantor, David Osher, Juliette Berg, Lily Steyer & Todd Rose (2018): Malleability, plasticity, and individuality: How children learn and develop in context[1], Applied Developmental Science, DOI: 10.1080/10888691.2017.1398649

To link to this article: https://doi.org/10.1080/10888691.2017.1398649

Published online: 24 Jan 2018.

APPLIED DEVELOPMENTAL SCIENCE
https://doi.org/10.1080/10888691.2017.1398649

Malleability, plasticity, and individuality: How children learn and develop in context[1]

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ABSTRACT

This article synthesizes foundational knowledge from multiple scientific disciplines regarding how humans develop in context. Major constructs that define human development are integrated into a developmental system framework, this includes—epigenetics, neural malleability and plasticity, integrated complex skill development and learning, human variability, relationships and attachment, self-regulation, science of learning, and dynamics of stress, adversity and resilience. Specific attention is given to relational patterns, attunement, cognitive flexibility, executive function, working memory, sociocultural context, constructive development, self-organization, dynamic skill development, neural integration, relational pattern making, and adverse childhood experiences. A companion article focuses on individual-context relations, including the role of human relationships as key drivers of development, how social and cultural contexts support and/or undermine individual development, and the dynamic, idiographic developmental pathways that result from mutually influential individual-context relations across the life span. An understanding of the holistic, self-constructive character of development and interconnectedness between individuals and their physical, social, and cultural contexts offers a transformational opportunity to study and influence the children's trajectories. Woven throughout is the convergence of the science of learning – constructive developmental web, foundational skills, mindsets (sense of belonging, self-efficacy, and growth mindset), prior knowledge and experience, motivational systems (intrinsic motivation, achievement motivation, and the Belief-Control-Expectancy Framework), metacognition, conditions for learning , cultural responsiveness and competence, and instructional and curricular design- and its importance in supporting in integrative framework for children's development. This scientific understanding of development opens pathways for new, creative approaches that have the potential to solve seemingly intractable learning and social problems.

Recent decades have witnessed an explosion of knowledge about how children develop into whole individuals, how they become learners, and how contextual factors nourish or hinder their development. This knowledge comes from diverse fields, including neuroscience, developmental science, epigenetics, early childhood, psychology, adversity science, resilience science, the learning sciences, and the social sciences. To date, such knowledge has existed largely in separate fields of research, and has not been integrated such that its profound relevance to developmental processes becomes both visible and directly applicable to the settings in which children grow and learn. As a result, important knowledge remains underutilized, contributing to persistent disparities, challenges, and inadequacies in our education systems, other child-serving systems, and the supports that we provide to families, practitioners, and communities.

The ability to realize the fullest potential of this knowledge is limited, paradoxically, by both the richness of the knowledge itself as well as the particular disciplinary structures, paradigms, and traditional incentives that have supported its creation (e.g., Kuhn, 1970). On the one hand, recent scientific advances include the accumulation of research, theory, and practice-based knowledge about the constructive, socially, and culturally embedded nature of development (e.g., Osher et al., 2016; Overton, 2015); advances in our ability to model idiographic, nonergodic biological, human, and social factors (e.g., Lerner, 2015; Rose,

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[1]References in this document are illustrative due to space constraints and do not represent all citations used to inform this review. Please see online extended reference list for the full set of citations that helped inform this review.

Rouhani, & Fischer, 2013), and advances in the array of methods and measurement tools now available (e.g., Entwisle, Hofferth, & Moran, 2017; van der Maas & Molenaar, 1992). On the other hand, prevailing disciplinary paradigms often reflect and beget delimited questions, measures, epistemes, and frameworks; research teams often lack disciplinary and/or cultural diversity; publishing in one's own disciplinary journal is often most highly rewarded; and funders often have narrow priorities. As such, there exists a great need to align and synthesize this increasingly vast, field-specific body of knowledge from biology, neuroscience, psychology, and the social sciences (e.g., Fedyk, 2015; Wilson, 1999) within a dynamic, holistic, contextualized framework. This integration can be accomplished in a manner that resolves apparent dichotomies, offers additional perspectives on existing research findings (Fischer & Bidell, 2006) and supports further research and development (R&D) efforts to better understand and support the healthy development and learning of all children.

Developmental systems theories (DST; e.g., Ford & Lerner, 1992; Overton, 2015), and associated dynamic systems mathematical models and methods, provide a rich architecture to do so (e.g., Cairns, Elder, & Costello, 1996; Fischer & Bidell, 2006; Mortimer & Shanahan, 2006; Overton, 2015). At its heart, DST is a general theoretical perspective on development, heredity, and evolution that departs from dichotomous views of development (Oyama, Griffiths, & Gray, 2001). It goes beyond "conventional interactionism" between genes and environment, producing a "truly *epigenetic* view of development" as an ongoing, constructive enterprise between the individual and multiple biological, psychological, and sociocultural systems and agents over time (Griffiths & Hochman, 2015, p. 2; Lickliter & Witherington, 2017). DST draws from numerous diverse fields and the work of many researchers, including those synthesized in this article.

DST enables an understanding of the rich complexity and "pervasive variability" in human development and activity that previous stage-based theories could not, and is a response to the need for a developmental theory that could explain patterns of both stability and variability in children's performance across diverse contexts (Fischer & Bidell, 2006, p. 314). It is built around two basic principles grounded in relational dynamic systems theory: (a) multiple characteristics of individuals and context collaborate to produce all aspects of behavior and (b) variability as well as stability in performance provide important information for understanding human development (Rose & Fischer, 2009). To generate meaningful, applicable data about patterns of human stability and variability, DST informs and makes use of mathematical methods and models from dynamical systems theory that allow for the study of mutually influential individual-context relations across the life span, with "context," including all levels of organization ranging from the inter-biological through the designed and natural environment, culture, and history (Overton, 2015).

Woven throughout this article and its companion article, DST provides a useful, flexible framework for seeing how multiple factors—both within an individual and his/her micro- and macro-environments—act together to shape how children learn, change, and systematically grow across the developmental continuum. It enables us to view, as information to study and act upon, the variability in behavior and performance that manifests daily in children and adults. DST underscores such variability as both the norm of human developmental processes and a source of valuable insight about the nature of development itself. It also helps us to better understand the drivers of that variability, explain observed variability in developmental range and the sequencing and pacing of skill acquisition, and identify stable patterns in variability that emerge and generalize over time. Ultimately, DST offers a means to organize and explain how complex relations involving our biological and physiological systems, social environments, and appraisals, interpretations, and internalizations of our experiences shape pathways across life and provide opportunities to optimize development.

Along with its companion article, this article synthesizes salient research regarding learning and development from individual fields, emphasizing where there is a convergence of evidence across multiple disciplines and lines of inquiry as well as where sufficient convergence does not exist. The findings presented in the article come from a variety of correlational, longitudinal, and causal studies; our approach was not to rely solely on causal evidence, but rather to triangulate across multiple sources. First, we solicited and reviewed recommendations for critical works from experts in the identified scientific fields. Next, we systematically and comprehensively identified and reviewed meta-analyses, peer-reviewed literature reviews, and handbook chapters that synthesized research over the last two decades. In some cases, we supplemented these sources with empirical and/or theoretical studies to nuance and validate our findings. Our sources either integrated an area of research with an established body of knowledge or presented findings that have been reproduced in multiple studies. We tempered our language where the literature shows less consistency because the science is more nascent and/or pronounced disagreements remain. To vet our source selections and validate our findings, we sent multiple drafts to experts in relevant fields and conducted two face-to-face invitational meetings (in October 2016 and June 2017) at which we presented the final research report and the companion manuscripts (Berg, Osher, Cantor, Steyer, & Rose, 2016; Osher, Cantor, Berg, Steyer, & Rose, 2017a, 2017b). This article and its companion piece update our findings and situate them within a powerful, unifying framework that integrates bioecological, relational, and contextual factors.

In this article, we first summarize the key findings of our study. We then synthesize and integrate a broad and deep literature of how human beings develop, situating this knowledge within a DST frame. We include the role of multilevel adaptive processes in shaping brain and complex skill development, with specific attention to the integration of affective, cognitive, social, and emotional dimensions; the progressive, holistic, individualized processes of learning, including critical foundational skills[2] such as self-regulation; the impact of adversity; and the opportunities suggested by research on attachment, relationships, and resilience. This article concludes with an integrated summary across these lines of research and introduces its companion article.

The companion article, "Drivers of Human Development: How Relationships and Context Shape Learning and Development," provides a still deeper exploration of context-individual relations within a dynamic developmental systems frame. It focuses on the role that relationships and micro- and macro-contextual relational, cultural, and structural factors play in supporting or undermining the healthy development of children and youth. Specifically, the companion article examines important contexts (e.g., families, schools) and actors (e.g., teachers, peers), the characteristics of such contexts and actors that affect development, social factors that undermine development (e.g., institutionalized racism, poverty, lack of support for adult caregivers), and strategies and contextual supports that can prevent or buffer the effects of those undermining factors. We believe that greater visibility into and understanding of these dynamic, integrated processes, coupled with the availability of new methods and measurement tools, can pave the way for substantial innovations in practice; for the supports we provide to teachers, families, and communities; and for the design of our education and child-serving systems more broadly.

Key findings

In synthesizing foundational knowledge from multiple scientific disciplines regarding how human beings develop in context, several overarching themes emerge. These themes are captured in Table 1.

Human development and epigenetics

"Positive development" emerges from the integration of several individual and contextual systems, from the biological and physiological to the cultural and historical (e.g., Spencer, 2007). As summarized by Fischer and Bidell (2006): "There is no separation of nature and nurture, biology and environment, or brain and behavior, but only a collaborative coordination between them" (p. 383).

In this contextual and relational developmental systems framework, the life cycle of an organism is not prefigured in a genetic program (Griffiths & Hochman, 2015; Moore, 2015; Witherington & Lickliter, 2016). Rather, genes act as followers, not prime movers, in developmental processes. As packages of biological instructions, genes require signals to determine which processes are carried out, with social and physical contexts influencing if, when, how, and which genes are expressed (Keating, 2016; Moore, 2015; Slavich & Cole, 2013). This conception of development runs counter to genetic reductionist views of evolutionary change that see genes as the primary mover in human development; to trait theories that posit that temperament, intelligence, and personality are determined by genes; and to conceptions of development as a static, fixed-stepped ladder (Fischer & Bidell, 2006; Lerner & Overton, 2017).

Epigenetic adaptation is the biological process through which the ecology of relationships, experiences, perceptions, and physical and chemical toxins get "under the skin" and influence lifelong learning, behavior, neural integration, and health (Bernstein, Meissner, & Lander, 2007). Chemical signals derived from environmental influence—"epigenetic signatures"—affect when and how genes are switched on and off, and whether the change is temporary or permanent. This process begins before conception (via parental experiences) and contributes to the transmission of behaviors and experiences to future generations (e.g., Keating, 2016; Meaney, 2010), as well as to qualitative changes in our

[2]In this article, we define foundational skills according to the definition provided by Stafford-Brizard (2016). Identified through research in the fields of neuroscience and child development, such skills are those that all children need for healthy development and learning, including the bonds that children make with adults, which provide emotional security; the skills to cope with and manage stressful conditions; and the regulation of emotion and attention to effectively engage and accomplish goals. Research has demonstrated that chronic stress and adversity, often experienced by children growing up in poverty, significantly impacts the development of brain regions responsible for such skills. As a result, many children do not enter school with skills for controlling impulses, focusing attention, or organizing thinking in a goal-oriented fashion.

Table 1. Summary of key findings.

Science of Learning and Development—Key Findings
I. Human development depends upon the ongoing, reciprocal relations between individuals' genetics, biology, relationships, and cultural and contextual influences.
• Human development occurs within nested, interlinked micro- and macro-ecological systems that provide both risks and assets to development and affect development both directly and indirectly.
• Epigenetic adaptation is the biological process through which these reciprocal individual-context relations create qualitative changes to the expression of our genetic makeup over time, both within and across generations.
• Genes are chemical "followers," not the prime movers, in developmental processes; their expression at the biological level is determined by contextual influences.
• The development of the brain begins prenatally and continues in one developmental continuum well into young adulthood. Opportunities for change, intervention, and growth exist across the developmental continuum, with particularly sensitive periods in both early childhood and adolescence.
• Developmental systems theory and associated dynamic systems mathematical models provide a holistic, contextualized framework within which to integrate diverse, field-specific scientific knowledge, enabling a deeper understanding of the developing brain and whole child in context.
• Intergenerational transmission is rooted in biological and social processes that begin before a child is born. Preventing the negative impacts of adversity can prevent the transmission of adversity and its many risks to development to future generations. Conversely, building individual and environmental assets can promote the intergenerational transfer of adaptive systems and opportunities.
II. Each individual's development is a dynamic progression over time.
a. The human brain is a complex, self-organizing system.
b. Neural plasticity and malleability enable the brain to continually adapt in response to experience, which serves as a "stressor" to brain growth across development.
c. Each individual's development is nonlinear; has its own unique pacing and range; features multiple diverse developmental pathways; moves from simplicity to complexity over time; and includes patterns of performance that are both variable and stable.
d. Whole child development requires the integration and interconnectivity—both anatomically and functionally—of affective, cognitive, social, and emotional processes. Though these processes—particularly cognition and emotion—have historically been dichotomized, they are inextricably linked, co-organizing and fueling all human thought and behavior.
e. The development of complex dynamic skills does not occur in isolation; it requires the layering and integration of prerequisite skills and domain-specific knowledge, as well as the influence of contextual factors.
f. Inter- and intra-individual variability in skill construction and performance—both of which are highly responsive to contextual influences and supports—is the norm. The optimization of development requires an understanding of both stability and variability in growth and performance.
III. The human relationship is a primary process through which biological and contextual factors mutually reinforce each other.
a. The human relationship is an integrated network of enduring emotional ties, mental representations, and behaviors that connect people over time and space.
b. Attachment patterns are formed through shared experiences of co-regulation, attunement, mis-attunement, and re-attunement. Though important in shaping future relationship patterns, early patterns remain open to change as children re-interpret, appraise, and re-appraise past experiences in light of new ones.
c. Developmentally positive relationships are foundational to healthy development, creating qualitative changes to a child's genetic makeup and establishing individual pathways that serve as a foundation for lifelong learning and adaptation.
d. Developmentally positive relationships are characterized by attunement, co-regulation, consistency, and a caregiver's ability to accurately perceive and respond to a child's internal state. These types of relationships align with a child's social-historical life space and provide protection, emotional security, knowledge, and scaffolding to develop age-appropriate skills.
e. The establishment of developmentally positive relationships can be intentionally integrated into the design of early care and educational settings, practices, and interventions.
IV. All children are vulnerable. In addition to risks and adversities, micro- and macro-ecologies provide assets that foster resilience and accelerate healthy development and learning.
a. Children's development is nested within micro-ecological contexts (e.g., families, peers, schools, communities, neighborhoods) as well as macro-ecological contexts (e.g., economic and cultural systems). These contexts encompass relationships, environments, and societal structures.
b. Adversity, through the biological process of stress, exerts profound effects on development, behavior, learning, and health.
c. Resilience is a common phenomenon wherein promotive internal and external systems integrate to facilitate the potential for positive outcomes, even in the face of significant adversity. As no two children draw from the same combination of experiences and supportive resources, resilience pathways are diverse, and yet can lead to equally viable and complex adaptation and, ultimately, well-being and thriving.
d. Environments and societal structures include the differential allocation of assets and risks, as well as the impact of differing belief systems about roles, talents, learning, and other factors viewed as driving personal success. While factors such as poverty and institutional racism makes poor outcomes more likely, family and community assets must be recognized, as they can protect children from short- and long-term negative consequences.
e. Adult buffering can prevent and/or reduce unhealthy stress responses and the resulting negative consequences for children. As such, building and supporting adult capacities are critically important priorities.
f. Early care and educational settings that provide developmentally rich relationships and experiences can buffer the effects of stress and trauma, promote resilience, and foster healthy development. Meanwhile, developmentally unsuitable and/or culturally incongruent contexts can exacerbate stress, hinder the reinforcement of foundational competencies, and impel maladaptive behaviors.
V. Students are active agents in their own learning, with multiple neural, relational, experiential, and contextual processes converging to produce their unique developmental range and performance. This holistic, dynamic understanding of learning has important implications for the design of personalized teaching and learning environments that can support the development of the whole child.
a. Diverse scientific fields converge to describe the holistic, complex, dynamic, contextualized processes that describe how children develop as learners.
b. A powerful organizing metaphor through which to understand the dynamic interrelationships governing children's development and knowledge and skill construction is that of the "constructive web."
c. Key factors that affect learning are internal attributes (including prior knowledge and experiences; well-developed habits, skills, and mindsets; and motivational and metacognitive competencies) and critical elements of the learning environment (including positive developmental relationships; environmental conditions for learning; cultural responsiveness; and rigorous, evidence-based instructional and curricular design).
d. Foundational skills such as self-regulation, executive functions, and growth mindset lay the groundwork for the acquisition of habits skills and mindsets including both higher-order skills (e.g., agency, self-direction) and domain-specific knowledge.
e. Motivation and metacognition are important, interrelated skills for effective learning. These competencies enable and encourage students to initiate and persist in tasks, recognize patterns, develop self-efficacy, evaluate their own learning strategies, invest adequate mental effort to succeed, and intentionally transfer knowledge and skills to solve increasingly complex problems.
f. Instructional and curricular design can optimize learning. Together, well-scaffolded, engaging, relevant, and rigorous content; personalized contextual supports in multiple modalities; and evidence-based, mastery-oriented pedagogies embedded in well-designed, interdisciplinary projects can balance what students already know with what they need and want to know.

(*Continued*)

Table 1. Continued.

Science of Learning and Development—Key Findings
g. Interpersonal and environmental conditions for learning (CFL) impact learning processes both directly and indirectly through their effects on cognition (e.g., cognitive load), student and teacher stress, and the relational dimensions of learning (e.g., attunement, trust). High-support conditions that recognize students' individual starting points and strengths can facilitate deeper learning while increasing developmental range, performance, and mastery.
h. Culture is a critical component of context. Cultural competence and responsiveness can address the impacts of institutionalized racism, discrimination, and inequality; promote the development of positive mindsets and behaviors; and build self-efficacy in all students, particularly those from culturally and linguistically diverse backgrounds.
i. Skill development occurs in all ecologies, cultures, and social fields. Next to the family, early care and education settings are the most important social contexts in which early development unfolds.
j. Research and development (R&D) efforts can be enriched, and progress accelerated, by employing dynamic systems analysis techniques and rapid-cycle improvement science methodologies to identify positive variation in developmental pathways and apply this knowledge at scale.
k. The design of education and other child-serving systems—and surrounding policy environments—cannot bet on the resilience of children alone. Rather, such systems must capitalize on the opportunities presented by the translation of developmental science to the design of contexts and practices, therein supporting a fully personalized approach to whole child development and the expression of human potential.
l. Dramatic improvements in outcomes and equity depend on public and political will. Sound policies to foster whole child development and practice must be grounded in rigorous science; implemented with quality; measured with an understanding of the formative progression of individual development; and adopted at scale, with cultural competence and equitable outcomes as explicit goals.

genetic makeup, both within and across generations (Moore, 2015; Slavich & Cole, 2013).

Brain structure and function

The human brain is a dynamic, living system that exists in relation to the other systems of the body. The human mind emerges from the development of the brain and exists to guide and interpret human activity (Fischer & Bidell, 2006; Siegel, 2012). The development of the brain is an experience-dependent process; in fact, neurons and neural tissue are the most susceptible to change from experience of any tissue in the body. Experience is a "stressor" to brain growth—throughout life, interpersonal experiences and relational connections activate neural pathways, generating energy flow through electrical impulses that strengthen connectivity among existing brain structures and create new ones. Experience shapes not only what information enters the mind but also the mind's ability to process that information. If experiences are interpersonally rich, predictable, and patterned, and if stressful experiences are not overwhelming, the brain becomes more connected, integrated, and functionally capable over time, increasing its adaptivity and resilience to future stress.

The brain is a complex system whose own internal processes organize its functioning—a property known as "self-organization." At birth, the infant's brain is the most undifferentiated organ in the body (Siegel, 1999). Genetic and epigenetic processes, in concert with early experience, shape neuronal connections and give rise to neural circuits that enable increasingly complex mental activities (Jablonka & Lamb, 2005; Moore, 2015; Slavich & Cole, 2013). The differentiation of neural circuits involves several processes, including neurogenesis (the formation of new brain cells), axonal growth, synaptogenesis (the formation and strengthening of synaptic connections), myelination (which increases "processing speed"), and the modification of receptor density and sensitivity of "receiving" neurons. As expressed in the Hebbian notion that "neurons that fire together, wire together" (Hebb, 1949), patterns of coactions with the environment result in the repeated activation of certain neural pathways, reinforcing them through subtle, rapid shifts in synaptic organization and strength. As these circuits become increasingly stable, they contribute to the emergence of enduring states of mind and increasingly complex thoughts, skills, and behavior in individuals. Meanwhile, such changes are balanced against pruning or cell death. Whereas pruning occurs naturally and is typically a healthy process, it can be disproportionately increased under prolonged stressful conditions. Enriched environments have the opposite effect, allowing for healthy pruning and enhanced neural integration (B. D. Perry, 2001; B. D. Perry & Szalavitz, 2017; Siegel, 2012).

The brain receives signals from different its regions, other systems throughout the body, and the outside world. The processing functions of the brain integrate information from these diverse sources into templates—representations of various types of stimuli—so that the brain gains meaning. Templates are drawn from prior affective, cognitive, social, and emotional experiences, including some that are not remembered consciously. The brain tags predicted, patterned experiences as "normal," integrates them into existing templates, and does not continue to focus on them. Meanwhile, when experiences are unpredictable, atypical, and/or unusually harmful, the brain cannot easily fit them into existing templates and pays attention to them. This tendency is particularly important with respect to templates generated by early traumatic experiences and/or other experiences of severe, recurrent stress; the brain can become habituated to negative templates, failing to identify them as abnormal (B. D. Perry, 2001; Siegel, 2012). Templates that are negatively biased by experiences of trauma and adversity can engender significant alterations in the pathways for complex skill construction, impacting their developmental range and the sequencing of important subskills (for further discussion, see section on the Science of Stress; Ayoub, Fischer, & O'Connor, 2003; Fischer, Bullock, Rotenberg, & Raya, 1993; Marshall, 2015; Mascolo & Fischer, 2015; Vygotsky, 1978).

Environmental and interpersonal experiences influence the growth of the brain throughout childhood and well into adulthood. Whereas the early period is particularly important for self-regulatory processes, middle childhood and adolescence provide new and unique opportunities for ongoing growth and reorganization toward more complex, integrated processes, and skills (Baltes, Lindenberger, & Staudinger, 2006).

Developing brain and dynamic skill development[3]

Dynamic skill development refers to the human brain's capacity to act in an organized way in a specific context (Fischer & Bidell, 2006; Mascolo & Fischer, 2015). Its driving force is the movement from simplicity to complexity; rather than emerging fully formed, skills are built up through practice in context in a constructive process over time. The brain's drive to complexity is consistent with the principles of nonlinear dynamic systems; such systems have self-organizing properties, are nonlinear, and are recursive over time (Molenaar & Nessleroade, 2014, 2015; Overton, 2015; Siegel, 1999).

A powerful metaphor for the development of complex dynamic skills is that of the "constructive web" (Bidell & Fischer, 1992; Fischer, Yan, & Stewart, 2003). Within the web, the strands represent pathways along which a child develops simultaneously, with pathways demonstrating responsiveness to emotion and support, the capacity for resilience, and variability in sequence, synchrony, and developmental range.

The web metaphor supports thinking about skill construction as an active process between multiple agents, with the resulting skills and behaviors ultimately joint products of the child and the resources and relationships that comprise his or her context (Fischer & Bidell, 2006). The metaphor emphasizes other core characteristics of skill development, including the fundamental principle of malleability; integration of affective, cognitive, social, and emotional dimensions; contextual (including cultural) specificity; and existence of both variation and patterns of order in variation. Consistent with the notion that "skills beget skills" (Heckman & Masterov, 2007, p. 447), the web metaphor recognizes the interdependent, hierarchical character of skill construction, with complex skills emerging as earlier skills are integrated into an inclusive whole. It enables an understanding that skills vary within individuals based on goals, emotional states, and contextual supports—producing a child's developmental range—and that a child's performance within that range can be optimized under conditions of high, personalized support (e.g., Bloom, 1984; Fischer & Bidell, 2006). Furthermore, it highlights the way in which skills are constructed for participation in specific tasks and contexts, and, over time, can and will generalize to other contexts (e.g., Fischer & Immordino-Yang, 2002). Finally, the web metaphor enables an understanding of individual and cross-cultural developmental diversity as alternative pathways for growth, rather than as deficits (Mascolo & Fischer, 2015).

DST and the related web metaphor stand at variance to static views of skill development as a ladder of fixed steps or stages. Although nomothetic-oriented developmental theories (e.g., stage conceptions proposed by Kohlberg, 1974 and Piaget, 1970) have helped to explain general (i.e., normative or average) features of children's thinking and behavior, they do not explain the widely observed departures from that consistency, nor do they present robust conceptions of between-person variation in intra-individual change (Emmerich, 1968; Lerner, 2017; Rose, 2016). When these theories are applied to children's development, a child's competence and performance can only be considered "low" or "high" relative to the one pathway deemed "normal." Nonetheless, such theories have shaped virtually all research and theory in cognitive development to date (Rose & Fischer, 2009).

By contrast, modern neo-Piagetian frameworks, which are consistent with the web metaphor, build upon the contributions of the Piagetian perspective to provide ways to study the longstanding "problem" of "pervasive variability" in human development and behavior (Fischer & Bidell, 2006, p. 314; Rose & Fischer, 2009). Using dynamic systems modeling, such frameworks allow us to observe multiple pathways with differential sequencing for the acquisition of a given skill, such as reading (Fischer, Rose, & Rose, 2007). Neo-Piagetian frameworks do not do away with the concept of stages entirely; indeed, skills may show stage-like jumps in development over certain time periods, particularly when a person performs at his or her optimal level under conditions of high support (Rose & Fischer, 2009). Ultimately, by enabling us to understand the

[3]This section draws from Fischer and Bidell (2006).

variability in pathways for complex skill development and performance, this approach paves the way for new, diverse educational practices and strategies that are personalized to learners' specific developmental trajectories and needs (e.g., Fischer, Bernstein, & Immordino-Yang, 2007).

The science of relationships and attachment

The relationships and experiences that guide the maturation of a child's developing neurobiological systems are themselves nested within larger micro- and macro-systems (Slavich & Cole, 2013). Relational integration —found in strong interpersonal connections that respect each person's autonomy and individuality while linking him/her in empathic communication with others—promotes neural integration, leading to strengthened linkages between existing synapses, regions, and functions that are critical for the development of more intricate brain processes and skills (Siegel, 1999, 2012). Positive developmental relationships are characterized by warmth, consistency, attunement, reciprocity, and joint activity, including the sharing and transfer of power and the scaffolding of learning (Center on the Developing Child, 2016; Li & Julian, 2012). In combination with positive (and positively perceived) experiences inside and outside the home (Center on the Developing Child, 2016), such relationships build strong brain architecture and are necessary for developing the affective, cognitive, social, emotional, and behavioral competencies foundational to development and learning—including development and learning that we often take for granted, such as language development (e.g., Sroufe, 2005). Stable, responsive relationships that encourage adaptive epigenetic signatures—and buffer experiences that contribute to maladaptive epigenetic signatures—represent powerful levers to optimize children's developmental potential.

Relational pattern making involves emotional responses, executive functions, reward and motivation systems, and sensorimotor systems; it occurs through sequences of attunement (sensing what others think and need), mis-attunement, and re-attunement (Kim, Strathearn, & Swain, 2016). In the first months of life, social synchrony—the coordination of social behavior between caregiver and infant in gaze, vocalization, affect, and touch—triggers biological synchrony in heart rhythms, oxytocin levels, and neural circuits, helping the caregiver and infant bond. During that time, the caregiver coregulates both the infant's and his/her own emotional arousal and physical needs (e.g., Kim et al., 2016). At toddler age, coregulation transitions to "caregiver-guided" regulation, reflecting the child's increasing ability to autonomously regulate the self and moving the child into progressively complex forms of interrelationship with environment and experience (Siegel, 2012).

The first year of life is especially important, as sensory, social, and emotional experiences offer opportunities to optimize foundational brain circuits. Early attunement balances excitatory and inhibitory systems in the brain; establishes templates for coordinated interpersonal behaviors, attitudes, and expectations about the self, others, and relationships; and enables the healthy development of neurobiological systems involved in cognition, stress modulation, and self- and emotional regulation (e.g., Feldman, 2015; Halfon, Shulman, & Hochstein, 2001; Knafo & Jaffee, 2013). Longitudinal research reveals that, absent effective intervention, early relational patterns between infants and parents influence how children later interact with teachers and peers (Sroufe, Egeland, Carlson, & Collins, 2005). The child-caregiver relationship continues to be an important influence as children develop (e.g., Sroufe, 2005), and key adults—parents, teachers, and other providers—have the capacity to attune to, reorient attachment to, and establish positive relationships with children and youth well into adulthood (e.g., Siegel, 2012).

Three developmental patterns characterize variation in infants' attachment: secure, insecure avoidant, and insecure anxious/ambivalent (Ainsworth, Blehar, Waters, & Wall, 1978; Shaver, Collins, & Clark, 1996). Disorganized attachment, which is associated with abuse and trauma, is often included as a fourth pattern (e.g., Cicchetti, 1990). In each pattern, children develop a working model of close relationships grounded in early experiences (Fischer & Bidell, 2006). Secure attachment with caregivers supports development through opportunities to (a) explore surroundings; (b) build language skills, through language-rich and responsive interactions; and (c) build social competence, through successful social interactions (e.g., Institute of Medicine & National Research Council, 2015).

Emotional or physical rejection, hostility, lack of appropriate responsiveness, and unpredictability can threaten healthy attachment, attunement, and relational and neural integration. One particularly significant cause of dysregulation is postpartum depression, which affects 10 to 20% of new mothers and between 4 and 26% of new fathers—and can be drastically higher for caregivers with histories of depression and stress hormone dysregulation (e.g., Kim et al., 2016). Caregivers experiencing postpartum depression and/or other adversities may demonstrate less capacity to buffer children's stress. In turn, prolonged periods of unbuffered, unregulated stress can disrupt the structure and functioning of critical neurobiological systems, including the brain, neuroendocrine system, and immune system (e.g., Bucci, Marques, Oh, & Harris, 2016). In this way, disorganized attachment endangers the development of foundational competencies, including executive functions, emotion recognition, and social information processing (e.g., Blair & Raver, 2016). Children with disorganized attachment patterns in their families may meet needs for later attachment in ways that are positive (e.g., strong adult and peer relations) or negative (e.g., early pregnancy).

Though theories of attachment often posit relatively fixed, one-way influences of emotions on development, new analytical tools provide greater visibility into more dynamic, complex relations (Fischer & Bidell, 2006) over time. Emotions can act as biasing forces that shape developmental pathways in both positive and negative ways (Ayoub et al., 2003). Although there is some stability in attachment patterns across individual development, children's working models remain open to change as they constantly appraise and reappraise past experiences in light of new relationships and experiences over time (e.g., Waters, Merrick, Treboux, Crowell, & Albersheim, 2000). Effective interventions can help families at risk for poor attachment relationships create positive, reciprocal, and nurturing relationships with their children (Furlong et al., 2012).

Science of self-regulation

Self-regulation skills and attributes—hereafter referred to under the umbrella term "self-regulation"—encompass a foundational set of competencies that aid in managing cognition, emotion, attention, and action, and support goal-directed behavior (e.g., Blair & Diamond, 2008). They are distinct from attitudes, beliefs, and mindsets, and involve multiple regulatory-related processes that range from automated physiological functions (e.g., circadian rhythm) to effortful, complex cognitive processes that unfold over time (Gestsdottir & Lerner, 2008). In this article, we include under the umbrella term of self-regulation the skills that comprise executive function (described further in the following sections) as well as other important regulation-related skills, such as effortful control, self-control, emotion and behavior regulation, and problem solving (S. M. Jones, Bailey, Barnes, & Partee, 2016). As with other dynamic, complex skills, self-regulation involves the coordination and integration of simpler, foundational skills (e.g., S. M. Jones et al., 2016). Separately and collectively, self-regulation skills contribute to adaptive affective, cognitive, social, emotional, metacognitive, and academic development processes; modulate experiences of stress; and enable productive engagement with the social and physical world (e.g., Almlund, Duckworth, Heckman, & Kautz, 2011; Dweck, Walton, & Cohen, 2011; Farrington et al., 2012; Nagaoka et al., 2015).

Executive functions are the set of neurocognitive attention-regulation skills involved in the conscious, goal-directed modulation of thought, emotion, and action (e.g., Blair & Diamond, 2008). Executive functions involve both top-down, intentional control of behavior as well as bottom-up, automatic reactions. Although precise definitions differ, common conceptions of executive function include the following components: attention control (voluntarily focusing on a specific task), cognitive flexibility (also called attention shifting, and commonly combined with attention control, switching from one task/demand to another, and considering others' perspectives), working memory (holding and manipulating information in the short term), and inhibitory control (mastery and filtering of thoughts and impulses to resist habits, temptations, distractions, and thinking before acting) (e.g., Center on the Developing Child, 2016; S. M. Jones et al., 2016).

Executive functions are necessary for more complex self-regulation-related skills, such as focus, self-control, perspective taking, communication, problem solving, making connections, taking on challenges, and self-directed, engaged learning (e.g., S. M. Jones et al., 2016). By preparing children to pay attention, follow rules, and actively engage in learning, executive functions are fundamental to learning readiness and school success (Zelazo, 2015). The development of executive function begins early and, like other elements of self-regulation, can be intentionally nurtured in early childhood, family, and school settings (S. M. Jones et al., 2016).

Self-regulation skills and attributes are critical for success in school and life, and there is a strong evidence base to support their vital contribution to short- and long-term social, emotional, cognitive, academic, financial, and health outcomes (e.g., Blakemore & Bunge, 2012; D. E. Jones, Greenberg, & Crowley, 2015; Mischel, 2014; Murry, Hill, Witherspoon, Berkel, & Bartz, 2015). Self-regulation skills are important prerequisites for skills associated with school readiness and higher-order learning, including decision making, problem solving, self-direction and organization, metacognition, learning from educational experience and practice, conflict resolution, perseverance, and resilience (e.g., Flouri, Midouhas, & Joshi, 2014; Gardner, Dishion, & Connell, 2008; S. M. Jones et al., 2016; Stafford-Brizard, 2015). Self-regulation-related skills also have powerful interpersonal implications, including promoting better relationships with teachers and peers (Raver, Garner, & Smith-Donald, 2007) and being seen by teachers as evidence of greater academic and social competence (Blair & Diamond, 2008). More broadly, self-regulation skills are associated with greater engagement in school, increased likelihood of graduating from college, and better health and wealth in adulthood (e.g., Zelazo, 2015).

Self-regulation is a useful example of a complex dynamic skill. It forms through the many interrelationships between and among various subskills and collaborating internal systems—interrelationships that are visible in the continuous feedback loop between emotion regulation, executive functions, motivation, and stress management. By stimulating the brain's self-organizing and reorganizing properties and integrating subsystems of skills, this feedback loop gives rise to the capacity to self-regulate and, ultimately, gives meaning to experiences, including stressful experiences. Indeed, the coordination and mutual reinforcement of these subsystems are thought to underlie the associations between self-regulation and important child outcomes, such as school readiness and academic competence (e.g., S. M. Jones et al., 2016).

Intentional self-regulation is initiated when a person consciously sets out to attain a goal and/or when routine activities are impeded. Intentional self-regulation includes well-researched skills such as effortful control, as well as the abilities to implement goal-related strategies (e.g., delayed gratification), optimize goals to align with personal and social values and desired abilities, and compensate in the face of blocked or lost goals. In the context of learning, intentional self-regulation is a constructive process whereby children set goals for their learning and then continue to monitor or control their cognition, metacognition, motivation, and behavior based on the assessment of success or failure in attaining their goals (Baltes, 1997; Gestsdottir & Lerner, 2008; S. M. Jones et al., 2016).

A growing body of evidence highlights the specific vulnerability of self-regulation skills to experiences of prolonged, unbuffered stress, as well as the importance and efficacy of intervening to intentionally develop self-regulation skills in children with impulsivity and attention issues (e.g., Barkley, 2012; Jimenez, Wade, Lin, Morrow, & Reichman, 2016; Shonkoff et al., 2012). Effective interventions that foster self-regulation and executive functions can prepare children who have experienced poverty-related adversities to successfully engage in learning and better succeed in school (e.g., Blair & Raver, 2014; Center on the Developing Child, 2016; Diamond & Ling, 2016).

Science of individuality

The science of individuality is grounded in dynamic systems theories (e.g., Thelen & Smith, 2006) and starts with the premises that individuals vary in how they learn, behave, and develop; that these processes vary according to context; and that there are patterns within that variability (e.g., Rose et al., 2013). The science of individuality has implications for diverse areas of research, from the growth of cancer cells to the evolution of literacy and social behavior to the developmental impact of adversity. Research grounded in this science enables us to move beyond explanations of global patterns of behavior to examine intra-individual differences in performance across diverse contexts, such as why a child can recite the alphabet for her parents at home, but not for her teacher at school (Rose & Fischer, 2009). The principles of this science are consistent with a range of fields, including research on the differential effects of interventions (Kellam, Koretz, & Mościcki, 1999), the historical and phenomenological factors that affect individual responses to adversities (Spencer, 2007), and the neurobiological factors involved in individual differences in plasticity and susceptibility to environmental influences (e.g., Johnson, Riis, & Noble, 2016).

A major implication of the science of individuality is that there is no single "ideal" developmental pathway for everyone; instead, there are multiple pathways to healthy development, learning, academic success, and resilience (e.g., Rose et al., 2013). Rather than study averages, research should start with a focus on understanding patterns in individual variation across contexts, and then build toward generalizable models of growth and learning—an "analyze, then aggregate" approach that captures the full richness and complexity of development (Rose et al., 2013).

Individual differences in plasticity and susceptibility to the environment can work in beneficial and/or harmful ways (S. W. Cole, 2014). For example, children with greater susceptibility may realize better outcomes when securely attached, yet realize more negative outcomes in contexts of disorganized attachment (e.g., Bakermans-Kranenburg & van IJzendoorn, 2007). The notion of differential susceptibility highlights powerful opportunities to intervene in the lives of children who experience the greatest dysregulation in the face of stress and adversity. These children also may be more malleable and stand to benefit most—in the context of supportive, enriched environmental supports and interventions (e.g., Johnson et al., 2016). A similar principle may be applied to developmental periods in which children demonstrate heightened plasticity to environmental influences.

To capture the range of variability in human development and skill acquisition, researchers should increasingly assess developmental pathways of different individuals through the Specificity Principle (Bornstein, 2017) and of different groups through dynamic nonlinear statistical approaches. The Specificity Principle views development as multidimensional, modular, and reflective of the interactive context of a child's life, producing distinctive pathways across time and at specific points in time. It addresses key questions about the moderating influence of practices and/or interventions —including the character of a specific effect, on a specific child, at a specific time, under a specific set of contextual conditions—to produce a specific set of competencies, behaviors, performance activities, or growth (Fischer & Rose, 2001; Rose et al., 2013). In a complementary manner, structural analyses and dynamic growth modeling enable the precise examination of source(s) of variation within nonlinear systems of hierarchical complexity, particularly when such methods address intersectionality (Fischer & Kennedy, 1997; Hartelman, van der Maas, & Molenaar, 1998; Singer & Willett, 2003; van Geert, 1991, 2003) and do not generalize findings to all human beings or all members of a group (M. Cole, 1996, Fischer & Bidell, 2006; Ghavami, Katsiaficas, & Rogers, 2016; Spencer, 2017; Wachs, 2015).

Science of learning[4]

The diverse scientific fields reviewed for this article converge around developmental principles that include malleability, variability, integration, specificity, relational support, cognition, emotion, and the importance of sociocultural context in the expression of human potential. This set of ideas is particularly applicable to the learning sciences, where DST provides a flexible, coherent organizing framework for integrating and sequencing diverse bodies of scientific work. Although much is known about the mechanics of learning (e.g., the benefits of spacing for practice, the use of multiple modalities, differentiated interventions to address domain-specific challenges, and important considerations regarding the type, frequency, and quality of feedback), the study of learning has extended in recent years to include influences on the development of the whole child in context (Lerner, Liben, & Mueller, 2015). With this focus has come a deeper understanding of the internal and external factors that co-act to impact children's learning readiness, processes, and performance. This section highlights some of the core insights in learning science that emerge from this dynamic, contextualized, holistic view. Ultimately, by shedding light on the diverse developmental pathways through which children acquire increasingly complex skills, develop motivation, identify intentionality as learners, and fully engage and perform, this integrated perspective can help to align instruction and school design with children's individual capacities and needs, therein facilitating developmentally oriented, culturally responsive approaches to domain mastery, the personalization of learning, and whole child development (Bloom, 1984; Fischer & Rose, 1994; Vygotsky, 1978).

Revisiting the constructive developmental web

As described previously, a powerful metaphor and framework through which to understand the dynamic interrelationships between children's development, knowledge, complex skill construction, and environmental supports is that of the "constructive web" (Fischer & Bidell, 2006). Applied specifically to learning processes, this framework positions the student as an active agent in his/her own learning; acknowledges the many relational, instructional, curricular, and environmental factors that support or undermine learning; recognizes that skills—derived from affective, cognitive, social, and emotional processes—do not emerge in isolation or a complete form, but rather codevelop hierarchically through multiple domain-specific practices in context; assumes the need for effective scaffolding, sequencing, and pacing within a child's unique developmental range; and ultimately characterizes students' learning trajectories as joint products of their individual attributes (both cognitive and affective) and the dynamic web of contextual supports surrounding him/her over time (Fischer & Bidell, 2006; Lerner, in press; Rose et al., 2013). This framework enables us to understand both inter- and intra-individual variation in skill construction and performance as the norm, not the exception, and positions us to employ research methods, mathematical models, and pedagogical practices that honor the diversity and holism of ongoing, dynamic relations between the child and his/her context and goals.

[4]Throughout this section, we define "content" in regard to facts, principles, and ideas. Following the tradition in cognitive developmental theory that knowledge involves (and is revealed by) internalized individual-context (e.g., Piaget, 1970) and externalized individual-context actions (e.g., Brandtstädter, 1998, 2006), we define "knowledge" as including the ability to use such content to decide and do complex tasks. Knowledge infuses learning and continuously reflects the coactions between the individual and his or her world.

The integration of affective, cognitive, social, and emotional processes in habits, skills, and mindsets to support learning

The constructive web highlights the integrative character of students' affective, cognitive, social, and emotional processes, which are both anatomically cross-wired and functionally interrelated (e.g., Overton, 2015). From this perspective, Overton's caution to avoid all splits is relevant. Although it is always possible to focus at a point in time on a specific feature of the integrated developmental system, such distinctions should not be enacted if they pose a risk to reintegrating all "pasts" into a synthesis that affords an understanding of the whole child.

Multiple neural systems—not merely those historically associated with cognition—contribute to core processes involved in learning, including attention, concentration, memory, and knowledge transfer and application. These molecular and behavioral interrelationships are particularly noteworthy in the case of connections between emotion and cognition, which many common cultural assumptions have artificially dichotomized (Fischer & Bidell, 2006; Rogoff, 2003, 2011). Cognition typically involves the processing or appraisal of information, whereas emotion involves the biasing or constraint of behavior and activities based on such appraisals (Fischer & Bidell, 2006). In this way, emotion and cognition co-organize all human thought and activity, and are inextricably linked. At the same time, children's social and affective bonds provide the "fuel" or energy flow for the development and use of the brain's self-organizing system and the resulting integration and cross-wiring of neural processes (Siegel, 1999). These interrelationships underlie research findings demonstrating the powerful influence of affective, social, and emotional processes on lower- and higher-order cognitive development and skill acquisition (e.g., Immordino-Yang & Damasio, 2007; Osher et al., 2016).

Emotions can have powerful effects on developmental pathways, including those specific to learning, whether caused by cultural norms, acute events such as trauma, or coactions among circuits of affective regulation (e.g., anxiety) and systems involved in body regulation (e.g., heart rate), sensation (e.g., physical pain), and cognition (e.g., executive control; e.g., Center on the Developing Child, 2016; Fischer & Bidell, 2006). Emotions further influence engagement and academic performance (Meyer & Turner, 2006) through their impact on confidence, motivation, persistence, self-control, anxiety, and curiosity (e.g., Immordino-Yang & Damasio, 2007).

Foundational skills and mindsets, such as self-regulation, executive function, intrapersonal awareness, a sense of belonging, self-efficacy, and a growth mindset, contribute to learning success and lay the groundwork for the acquisition of higher-order skills, such as agency, resilience, and self-direction (Stafford-Brizard, 2016), all of which underpin the acquisition of domain-specific skills. Both lower- and higher-order skills are malleable and can be intentionally developed (Osher et al., 2016). Collectively, the integration of foundational affective, cognitive, social, and emotional processes into habits, skills, and mindsets that support learning is critical to students' school and life success (e.g., Immordino-Yang & Damasio, 2007).

Skill development and acquisition can occur in all ecologies of human development (Bronfenbrenner, 2005; Bronfenbrenner & Morris, 2006), including the school, family, out-of-school contexts, workplace, and broader social fields and cultural spheres (Boell & Senge, 2016). In a similar way, the fuel for students' interest in—and work to master—domain-specific skills can be generated from multiple sources. This understanding of skill construction acknowledges that although all children do not have the same starting point in life, nor do they follow identical pathways, they can nevertheless succeed in developing higher-order complex skills. Like other complex skills, higher-order cognitive skills have pathways that can be nurtured if grounded in an understanding of the importance of foundational skills and the specificity and variability of developmental pathways (Stafford-Brizard, 2016).

Prior knowledge and experience

These integrated processes and skills influence and are influenced by other internal resources that children bring to learning, including *prior knowledge and experience*. Students are not "blank slates"—they are active agents who bring to school prior knowledge and experiences (whether correct or incorrect) of how the world works; beliefs about themselves, their intelligence, and learning; epistemological beliefs; domain-specific knowledge; and cultural knowledge, skills, and schema that may be incomplete or inconsistent with instruction, language, and discourse practices (e.g., Ambrose & Lovett, 2014; Brandtstädter, 1998, 2006; Yeager et al., 2014). Shaped by earlier developmental experiences, prior knowledge encompasses automated beliefs, attributions (including attributional errors) from the past, conscious and unconscious knowledge (including knowledge that needs to be corrected), and metacognitive and cognitive skills (e.g., Ambrose & Lovett, 2014; Berliner & Kupermintz, 2016; Clark, 2006; Clark & Saxberg, 2018).

Prior knowledge, experience, and skill affect how students receive and process novel information (e.g., Nihalani, Mayrath, & Robinson, 2011). Teachers can leverage prior knowledge, experience, and interests to enhance motivation, engagement, critical thinking, problem solving, and learning more generally; in turn, when such factors are not considered, students may become less engaged (Ambrose & Lovett, 2014). Neural integration and the mastery of new information are more likely to occur when scaffolding is informed by students' prior knowledge, allowing for the creation of individualized, relevant conditions for growth, reflection, and practice to accelerate mastery (Deans for Impact, 2015).

Motivation

Motivation is a psychological process that determines whether people begin a task, persist at it once they have begun, and invest adequate mental effort to succeed (e.g., Clark, Howard, & Early, 2006; Larson & Rusk, 2011; Pintrich & Schunk, 2002). Motivation involves beliefs, values, interests, goals, drives, needs, reinforcements, and identities (Oyserman & Destin, 2010; Wigfield et al., 2015); influences choice, persistence, and effort (Wigfield et al., 2015); and is essential for engagement and learning. Intrinsic motivation is associated with deeper focus, creativity, confidence, and achievement (Patrick, Turner, & Strati, 2016). In fact, conservative estimates posit that for adolescents and adults, academic motivation accounts for approximately 30% of learning, as well as the transfer and/or application of what has been learned (Colquitt, LePine, & Noe, 2000). Though relatively little attention has been paid to supporting the full range of motivation processes key to learning and achievement (Clark & Saxberg, 2018), intervention efforts that target motivational systems show great promise (Lazowski & Hulleman, 2016; Paunesku et al., 2015; Yeager & Walton, 2011).

Motivation is a key component of all learning processes, and it shapes and is shaped by foundational skills and elements of learning environments. Competency-related beliefs—beliefs about what one is capable of with regard to a particular task or situation, including self-efficacy—are key to self-regulated behavior and learning. Such beliefs vary by task and are derived from both past experiences with similar tasks and environmental influences (Wigfield & Eccles, 2000). When students feel a sense of efficacy, believe that their intelligence and ability can be improved through effort, and feel in control of their learning, they are more motivated to learn and, ultimately, more effective learners (e.g., Deci & Ryan, 1985; Dweck & Molden, 2017). Specifically, beliefs about personal influence and control impact students' expectations for their own success, which in turn affect their likelihood of succeeding at a given goal (e.g., Schunk, Pintrich, & Meece, 2007).

Other beliefs and values play an essential role in motivation. Task-related values—students' beliefs about the importance and personal and societal utility of a given task—have been associated with important academic outcomes, and become more differentiated (and decline) as students move through school (Marsh, Martin, Yeung, & Craven, 2017; N. Perry, Turner, & Meyer, 2006). Children's goals for learning and other activities, interest in learning, and valuing of achievement also are central to achievement motivation (Wigfield et al., 2015). Purpose, defined by Damon, Menon, and Bronk (2003) as "a stable and generalized intention to accomplish something that is at once meaningful to the self and of consequence to the world beyond the self" (p. 121), contributes to greater prosocial behavior, self-esteem, achievement, and moral commitment (Damon et al., 2003). Students who see a prosocial purpose to a particular academic task are more likely to persist, despite difficulty or boredom (Yeager et al., 2014). Along similar lines, hopeful expectations for the future influence how students process information and, in turn, regulate their behavior (Schmid, Phelps, & Lerner, 2011).

Motivational beliefs, goals, and identities influence and are influenced by the contexts in which young people learn and develop (N. Perry et al., 2006; Schmid et al., 2011). Motivational systems are activated when the person-context relationship is adaptive for both the individual and the context (Lerner, 2006; Overton, 2010), and tailored external supports and sense of belonging can reinforce self-regulated learning behaviors (e.g., Furrer, Skinner, & Pitzer, 2014; Walton & Brady, 2017). Identities play a powerful role; students are motivated to think and act in ways that are congruent with their identities, which, in turn, are contextually situated (e.g., Oyserman, 2009).

A useful framework through which to understand the many factors that contribute to motivational challenges is the Belief-Control-Expectancy (B-C-E) Framework (e.g., Clark & Saxberg, 2018; Eccles & Wigfield, 2002; Schunk et al., 2007; Wigfield & Cambria, 2010). Each of the four factors in the framework—values, self-efficacy, emotions, and attribution errors—influences beliefs about control and expectancies for success, and can impact a student's ability to start, persist, or apply sufficient mental effort to complete and succeed at a task. Using the B-C-E

Framework to (a) distinguish motivational issues from learning strategy problems and (b) identify their specific causal factor(s) enables the application of targeted evidence-based strategies to more effectively address motivational challenges (e.g., Clark et al., 2006).

Metacognition

Metacognition involves the awareness of one's own thinking and learning—that is, one's thoughts about one's thoughts. Metacognitive skills are complex dynamic skills that depend upon foundational self-regulation and executive function skills. Collectively, these skills enable students to regulate their bidirectional relations with their contexts by processing, manipulating, and refining information; organize and recognize patterns in information; evaluate their thinking and learning strategies; intentionally transfer knowledge to new situations; and apply knowledge to solve increasingly complex problems (e.g., Flavell, 1979; Lai, 2011). When sufficiently developed, metacognition enables learners to select strategies that are situationally appropriate and relevant to particular disciplines and learning tasks (Conley, 2014). Moreover, engagement in metacognitive processes actively supports ongoing neural integration and enables students to learn from their mistakes (e.g., Marcovitch & Zelazo, 2009). In a way, learners become their own evidence-based instructional designers, with increasing abilities to apply knowledge in different (and not always optimal) learning environments.

Metacognitive abilities also can enhance motivation. Students are more motivated to learn and be more effective learners when they apply strategies effectively, seek help appropriately (e.g., Dweck & Molden, 2017), and identify strengths and weaknesses in their own learning (Koriat, 1993). The ability to distinguish between short- and long-term learning goals also is important for sustaining motivation over time while remaining responsive to short-term performance pressures (Hattie, 2011).

Pedagogical strategies that promote metacognition leverage constructivist and curriculum-based opportunities, engagement, and self-direction (Conley, 2014; Ellis, Denton, & Bond, 2014). Such strategies encourage students to reflect on their affective states, how well they are learning, and how new knowledge fits into existing knowledge, increasing self-awareness, expertise, and the ability to transfer knowledge to new situations and problems (Clark, 2006; Pintrich, 2002).

Conditions for learning

The internal resources that children bring to learning—including prior knowledge and experience, integrated neural processes, motivation, and metacognitive skills—are nested within the conditions for learning (CFL) that they experience. CFL encompass the relational dimensions of learning (including trust, attachment, attunement, and congruent perceptions with adults and peers), physical and emotional safety, and a sense of belonging and purpose (Osher & Berg, in press; Osher & Kendziora, 2010).

CFL affect learning both directly (e.g., effects on working memory, cognitive load, developmental range) and indirectly (e.g., effects on teacher stress, student stress, ability of each to attune to the other; Swearer, Espelage, Vaillancourt, & Hymel, 2010). On the one hand, negative CFL such as perceptions of a lack of safety can impact learning by heightening anxiety, triggering the stress response system, and affecting working memory, attention, and concentration (Shackman et al., 2006). On the other hand, positive CFL, such as the experience of teacher attunement and support, can enhance engagement and optimize absorption, focus, and enjoyment (e.g., Schmidt, Shernoff, & Csikszentmihalyi, 2014). Moreover, components of CFL can work together to produce classroom climates that welcome effort and errors, promote perseverance, and focus on mastery as opposed to exclusively short-term performance (Hattie & Yates, 2014). Students learn best when CFL promote motivation, engagement, and purpose; ensure emotional, physical, and identity safety; and foster connection, respect, support, and challenge (Garibaldi, Ruddy, Osher, & Kendziora, 2015; Hammond, 2016; Lachini, Berkowitz, Moore, Astor, & Benbenishty, 2016; Steele, 2010; Wentzel & Muenks, 2016).

At the core of CFL are the presence of positive developmental relationships (defined in the earlier section on relationships and attachment; Li & Julian, 2012) between students and teachers. These mutually reinforcing relationships between and among students, teachers, and peers are entwined with the student's neural response to the experience of learning; the degree to which students are able to tap their affective, cognitive, social, and emotional resources; and students' willingness to take academic risks (Hammond, 2016). Positive developmental relationships are particularly significant for students whose developmental pathways have been altered due to trauma and/or chronic stress.

Similarly, students' mindsets and behaviors are affected by school staff members' perceptions of them, which, in turn, are influenced by teachers' own mindsets. Teachers' language can impact students' self-concept, engagement, motivation, capacity to take on and persist though challenging academic tasks, and behavior in positive or negative ways (Clark, 2006; Kellam &

Rebok, 1992; Master, Butler, & Walton, 2017). In the context of negative perceptions, students find it harder to engage, become more easily frustrated, develop lower self-concepts and expectations, and lag academically (Kaplan, Gheen, & Midgley, 2002; Osher & Kendziora, 2010). Such experiences may be particularly common for culturally and linguistically diverse students from nondominant or marginalized groups who face school contexts in which choice and control are limited, the belief that effort matters is undermined, and racial stigma is evoked in ways that reinforce negative racial narratives and identities (e.g., Hammond, 2016; Oyserman, Destin, & Novin, 2015; Oyserman & Lewis, 2017; Rogoff, 2003; Steele, 2010).

Cultural responsiveness and competence

Cultural competence and responsiveness can help build CFL that support learning and development for all students. Cultural competence—which in the case of schools involves congruent attitudes, behaviors, and policies that enable educators to work effectively in multicultural interactions (King, Sims, & Osher, 2007)—can help schools and other child-serving systems to systematically address the assumptions, disconnects, adversities, and challenges (including those created by schools themselves) faced by culturally and linguistically diverse students and families. Critical barriers include both institutionalized processes (e.g., resource allocation, rituals, policies) and interpersonal behaviors (e.g., harassment, micro-aggressions, negative stereotyping, assumptions of prior knowledge) that collectively heighten anxiety, negative thinking, and stress; place extra demands on working memory and cognitive resources; drain energy available to address tasks (e.g., Pennington, Heim, Levy, & Larkin, 2016); and impact health and learning (Artiles, Kozleski, Trent, Osher, & Ortiz, 2010; LeBrón, Schulz, Mentz, & White Perkins, 2015; Pennington et al., 2016; Solórzano, Ceja, & Yosso, 2000). Further challenges can arise when students are expected to master new content without the explicit or implicit culturally embedded knowledge that those from dominant groups benefit from and that teachers may take for granted (e.g., Clark, 2006). Cultural dissonance makes it harder for students to perceive themselves as learners (or successful learners) and to visualize the connection between their schoolwork, current lives, and promising futures (Ambrose & Lovett, 2014; Oyserman & Destin, 2010).

Cultural competence contributes to effective learning by (a) addressing or preventing factors that directly interfere with students' learning (e.g., school discipline polices that exacerbate the impacts of implicit bias), and (b) creating supportive environments and personal readiness in adults to address cultural disconnects and disabling conditions (Perso, 2012). Although necessary, cultural competence is not sufficient to create conditions for deeper learning and domain-specific mastery.

Culturally responsive approaches can support both the relational and neurobiological conditions for engaged, rigorous leaning through attuned, context-sensitive communications between the teacher and student (Gay, 2000; Hammond, 2016). These approaches counter subtractive approaches (Valenzuela, 1999) that ignore students' existing assets, fail to appreciate them, or view them as negative departures from the norm (Mistry & Dutta, 2015). Instead, culturally responsive approaches promote effective information processing by using cultural knowledge as a scaffold to connect existing knowledge to new concepts and content (Hammond, 2016; C. D. Lee, 2010), drawing on both the learner's resident long-term-memory mastery as well as the motivation that comes from using previously developed expertise. At the same time, culturally responsive approaches support learning by reducing educators' likelihood of overestimating students' prior knowledge or familiarity with context-specific, culturally embedded schemas (Crosnoe & Benner, 2015; C. D. Lee, 2010; Murry et al., 2015).

Like well-designed social-emotional learning (SEL) and CFL, culturally responsive approaches create conditions for engagement in productive, critical struggles with academic content by creating emotionally, intellectually, and identity-safe environments. Culturally responsive strategies can address the impacts of institutionalized racism and discrimination, including diminished opportunities to learn (e.g., lack of access to advanced courses) and dissonance between pedagogy and students' individual experiences, cultural capital, and needs (e.g., Gay, 2000; Ladson-Billings, 2006; Spencer, Swanson, & Harpalani, 2015). Culturally relevant pedagogues understand that students must learn to navigate between home, community, and school and to develop the cultural competence that enables them to navigate the "within and between" social situations that have culturally embedded role expectations (Goodnow & Lawrence, 2015). Teachers must find ways to equip students with the knowledge needed to succeed in a school system that produces inequitable and dispiriting burdens (Delpit, 2006; Ladson-Billings, 2006; Urrieta, 2005). Multiple studies suggest that culturally responsive approaches increase students' motivation to learn; interest in content across literature, science, mathematics, and social studies; ability to engage content area discourses; and perceptions of themselves as capable students (Aronson & Laughter, 2016).

Instructional and curricular design

Instructional and curricular design should foster active student engagement, combat the pedagogy of poverty (e.g., Freire, 1970; Haberman, 1991), and support rigorous academic capacity and efficacy. Such design begins where students' mastery starts, promoting the acquisition and retention of knowledge in domain-specific areas and the development of increasingly complex cognitive and metacognitive competencies. These efforts should acknowledge students' prior knowledge and experiences while expanding over time into new areas; foster student voice and agency; and feature engaging, relevant content, well-scaffolded instruction that supports the personalization of learning (including collaborative learning opportunities), and well-designed interdisciplinary projects. Reflecting the Aristotelian concept of phronesis (Irwin, 1999),[5] instructional design should seek to provide the right amount of challenge, rigor, support, feedback, and formative assessment to drive and accelerate the developmental range and performance of individual students.

To achieve such goals, teachers must utilize practices that balance what a specific student already knows he/she wants and needs to learn, and the degree of challenge presented. Practices of this kind were initially conceptualized by Vygotsky (1978) as the zone of proximal development (ZPD), and later expanded upon by Bloom (1968) through the mastery learning framework (see Bloom, 1968; Guskey, 2005, for further elaboration of mastery learning). This balance addresses knowledge acquisition and retention in long-term memory, which are important for the development of both critical thinking and mastery (Schwartz et al., 2016; Willingham, 2009). Critical thinking processes (including reasoning and problem solving) are intimately informed by and interconnected with background knowledge; "thinking well requires knowing facts" (Willingham, 2009, p. 8). In addition to supporting and enabling critical thinking, knowledge acquisition and retention in long-term memory—connected to instructional practices drawing upon what is already stored in long-term memory—can enable the student to achieve greater fluency in the present, free up working memory, provide an enriched base for future learning, and accelerate developmental range and the path to mastery (Schwartz et al., 2016; Willingham, 2009).

Content choice must be addressed in instructional and curricular design; different curricula domains (e.g., mathematics vs. literature) may involve variation in actions needed to develop knowledge effectively. Nevertheless, across content areas, material that is presented in multiple modalities and contexts allows for greater, more integrative practice, influencing pacing and the development of fluency (Willingham, 2009). Importantly, students find it easier to acquire new content knowledge in reference to prior knowledge (Bransford, Brown, & Cocking, 2000; Deans for Impact, 2015) and benefit from opportunities to explore content at their own pace, based on their unique interests and developmental skill level (Rose, 2016).

Integrated instructional design successfully combines affective, cognitive, social, and emotional processes with curricular content, and promotes academic growth (Durlak, Weissberg, Dymnicki, Taylor, & Schellinger, 2011; S. M. Jones & Bouffard, 2012; Osher et al., 2016). Examples include well-designed project-based learning, in which students may both build and use their masteries to create a realistic product and present it to an audience; well-designed service learning, in which students contribute to a community; and well-designed collaborative learning, in which students develop a sense of interdependence and individual accountability (Hammond, 2016).

Effective instructional design is grounded in an understanding of the differing ways in which experts and novices learn (Fischer & Bidell, 2006; Merrill, 2002, 2006). Novice learners benefit from factual knowledge and explicit guidance. As such, the development of effective designs may best begin by identifying learning outcomes aligned with how experts decide on and do complex tasks. This information can serve as a basis for data-gathering processes that shed light about whether and how specific learners are progressing in directions that are consonant with the actions of experts, and instructional designs that accelerate learners' growth along pathways that increasingly mirror those of experts.

Novice learners process and retrieve knowledge less efficiently than experts (e.g., Kalyuga, Ayres, Chandler, & Sweller, 2003). Nevertheless, if informed by methods such as cognitive task analysis, well-calibrated instructional and curricular design can help to reduce *cognitive load*—the amount of mental effort required in using working memory—as well as expand the limits of working memory (Alloway, 2006). Thoughtfully organized frameworks that combine intentional, explicit instruction with hands-on learning experiences also

[5]Aristotle discusses phronesis as "practical wisdom"—knowledge that guides a person to enact the right moral virtue, in the right amount, at the right time, and in the right place. Simply, phronesis is knowing what is best to do, and how to do it, in a specific setting.

may enable novice learners to see the "whole picture," further facilitating the retrieval and application of new concepts and deepening knowledge (e.g., Merrill, 2007). Although recognizing novice learners' unique needs and alleviating cognitive load are important, such considerations should not result in ultimate oversimplification; information should be presented over time with increasing relevance and rigor (Paas, Renkl, & Sweller, 2004).

As students build new capacities, support needs to be calibrated to their changing levels of engagement, goals, and expertise (Hattie, 2011; Hattie & Donoghue, 2016; Kalyuga, 2007; C. H. Lee & Kalyuga, 2014). Accordingly, instructional design should simultaneously focus on the development of foundational cognitive, social, and emotional competencies (Stafford-Brizard, 2016); provide "desirable difficulties" that balance short-term challenges against long-term retention and transfer (Clark & Bjork, 2014); and address the distinct brain states supporting two different types of learning—one that supports task orientation, and another that supports imagination, creativity, and meaning making (Gotlieb, Jahner, Immordino-Yang, & Kaufman, 2016).

In sum, school and instructional design should capitalize on the opportunities presented by the translation of developmental science to practice—opportunities that require much closer, bidirectional collaborations between researchers and education practitioners (Stafford-Brizard, Cantor, & Rose, 2017). Such collaborations also should utilize dynamic quantitative and qualitative methods to address the jaggedness of learning—the multiple and nonlinear pathways that individual children take to develop complex skills and knowledge (Fischer, 2009; Molenaar & Nessleroade, 2014, 2015; Rose et al., 2013). Research may be enriched by employing dynamic systems-based data analytic techniques in combination with methods like crowdsourcing, analyses of positive deviance, and rapid-cycle improvement science methodologies. Collectively, these approaches can strengthen our ability to understand individual variation in students and the developmental pathways toward mastery learning.

Illustrative example and implications

There are many possible illustrations of this complex integration—and, indeed, the multiplicity of examples is precisely the challenge of "learning engineering," or designing real-world, complete educational environments from the wide array of research cited in this article. A variety of research syntheses on domain-specific possibilities for instruction exist (e.g., National Mathematics Advisory Panel, 2008; National Reading Panel, 2001; and practice guides from the Institute of Education Sciences[6] all of which need to be framed in the context of developmental, motivational, and meta-cognitive considerations when constructing real-world instruction in context.

The acquisition of reading skills serves as one example of dynamic, context-embedded skill construction. Reading skills are embedded in and influenced by the multiple literacies children are exposed to and will need to acquire, as well as the cultures in which children are situated. As with other skills, there is significant variability—and multiple cultural influences—in the pathways by which children develop these literacies. Although the nature of literacy has since expanded (e.g., internet-related literacies), Knight and Fischer's (1992) identification of multiple pathways remains useful when we think about the development of particular literacies. When children's performance is assessed relative to the most common pathway, it can only be viewed as either "normal" or "delayed," with remediation directed toward speeding up progress along the "normal" pathway. And, yet, we now know that slower readers can be viewed as following *different* pathways to become skilled readers, rather than as "delayed" based on a premised universal pathway. In this way, the constructive web supports re-conceptualizing of developmental and cultural differences as alternative pathways, rather than deficits. Simultaneously, it highlights the opportunity for instructional and curricular designs that address these alternative pathways and, in so doing, channel student effort toward the pathway where individual progress will be greatest, therein optimizing developmental range and literacy development for all students (Fischer et al., 2007; Knight & Fischer, 1992; Wold & Katzir-Cohen, 2009).

The example of literacy development highlights principles that can generalize to other domain-specific learning activities and outcomes, most notably, the profound role of developmental variability, including unique pathways, pacing, and range, and the need to situate and integrate fundamental neural processes in contexts that promote developmental progression. In turn, Bloom's two sigma finding (Bloom, 1984) provides a compelling illustration of what is possible if we use the principles of developmental variability, individuality, and integration to "design" contexts in which individual children can thrive as learners. Bloom found that students who received effective one-on-one tutoring through a mastery learning framework performed two standard deviations better than students who did not. By substantially increasing students' individual contextual support (Fischer & Kennedy, 1997; Fischer & Yan, 2002) and

[6]See, https://ies.ed.gov/ncee/wwc/PracticeGuides.

enabling co-participation and sharing of psychological control of learning tasks (e.g., Shanahan & Shanahan, 2008), high-support, mastery-oriented pedagogical strategies can thus extend students' performance (from functional to optimal) within their developmental range and, ultimately, heighten achievement. Under the right conditions, skills constructed in this way also can stabilize and generalize to new contexts over time (Fischer & Farrar, 1987; Fischer & Immordino-Yang, 2002).

The constructive web enables us to better understand and link the principles of proximal development defined by Vygotsky (1978), the approach to accelerated mastery defined by Bloom (1984), the context dependency described in Bornstein's specificity principle (Bornstein, 2017), and the constructivist approach to developmental variation seen in the work of Fischer, Rose, and colleagues (e.g., Fischer & Bidell, 2006; Mascolo & Fischer, 2015; Rose & Fischer, 2009). Each body of work employs a dynamic developmental lens to emphasize the power of context to co-act with the individual child and his/her domain-specific mastery to optimize outcomes for all children.

The learning sciences illustrate convergence and integration of micro-developmental processes—the construction of new skills for "proximal processes" (Vygotsky, 1978)—and macro-developmental processes—larger scale processes in which many constructive activities come together to form complex skills that stabilize and generalize to new contexts over time. The course of individual human development is such that although people develop over the long term, critical learning occurs over shorter time horizons through an accumulation of diverse, context-dependent, nonlinear growth experiences. The range of students' skills—and, ultimately, their potential as human beings—can be significantly influenced through the intentional design of learning environments and experiences to optimize their development under conditions of high, personalized support (Fischer & Bidell, 2006).

Education design and policy cannot bet on the resilience of individual children alone. It must address the key drivers of positive developmental and learning outcomes, which include the intentional development of integrated habits, skills, and mindsets; effective, rigorous pedagogy, and curricular and instructional design; and the creation of classroom and school environments that support personalization of learning and the development of the whole child.

Science of stress

Like the human relationship, stress is a model through which the biological and contextual influences mutually reinforce each other at multiple levels, including the level of the cell (S. W. Cole, 2014). When we are threatened, our bodies protect us by a stress response, during which hormonal and neurochemical systems are activated in the body. The hypothalamic-pituitary-adrenal (HPA) axis produces cortisol and the sympathetic-adrenomedullary (SAM) system produces adrenaline, two hormones that prepare the body to meet threats by increasing heart rate, blood pressure, inflammatory reactivity, and blood sugar levels (Center on the Developing Child, 2016). This "fight, flight, or freeze" response heightens vigilance and alertness while reducing nonessential functions such as complex thinking. Although lifesaving in the face of acute danger, these responses can cause damage when activated over long periods of time—particularly to the developing limbic and immune systems (Center on the Developing Child, 2016).

The American Academy of Pediatrics has described three types of stress responses—positive, tolerable, and toxic. A positive stress response is characterized by mild and/or brief elevations in stress hormones, heart rate, and blood pressure, and is part of healthy child development. A tolerable stress response activates the body's alert systems to a greater degree due to more severe or long-lasting threats, but in the presence of supportive, buffering relationships, it can be brought to baseline quickly, preventing long-term physiological effects. Toxic stress responses, on the other hand, occur when stress exposure is frequent, prolonged, and unbuffered by adequate adult support. The resulting chronic elevation of stress hormones can disrupt the maturation of children's developing brain architecture and physiological systems, with major implications for later life health, learning, and well-being (Center on the Developing Child, 2016; Felitti & Anda, 2010).

Exposure to chronic, unbuffered stress is associated with changes in brain architecture, including smaller volume of the prefrontal cortex and hippocampus, larger volume of the amygdala, altered brain chemistry, and heightened production of inflammatory hormones, including cortisol and cytokines. A dysregulated stress response system is one of the few systems of the body that can affect the development of all four brain structures—brainstem, diencephalon, limbic system, cortex—and, in particular, the integration of these structures (e.g., Siegel, 2012). Indeed, research on the consequences of developmental trauma points to impairments in the growth of key integrative structures, including the corpus callosum, hippocampus, and prefrontal cortex (e.g., Teicher, Samson, Anderson, & Ohashi, 2016).

In addition to their effects on specific brain structures and patterns of connectivity, traumatic experiences like abuse and neglect can result in the emergence of highly distinctive developmental pathways (Fischer & Bidell, 2006). Contrary to a general global bias toward the positive in thought and action (particularly in attributions toward oneself), children exposed to high concentrations of adversity often have developmental webs that are biased toward the negative (e.g., Ayoub et al., 2003). This negative bias can have pervasive impacts on development, resulting in characterizations of the self, others, and relationship patterns in negative terms, and the use of dissociation skills to cope with trauma, among other effects. As children exposed to adversity continue to develop, their existing working models of relationships—powerfully organized by past traumas—frequently generalize to future experiences and interactions with others (Fischer & Bidell, 2006). Importantly, contrary to some characterizations, such developmental pathways are complex and sophisticated, and remain open to change across the course of development (Fischer & Bidell, 2006).

An increasingly common framework for categorizing and assessing cumulative risk in children's exposure to chronic stressors is that of adverse childhood experiences (ACEs; Felitti et al., 1998). The common definition of ACEs involves stressful or traumatic events experienced before age 18 that fall into three broad domains: abuse, neglect, and household dysfunction (e.g., Burke Harris & Renschler, 2015). The original ACE categories are physical, emotional, and sexual abuse; physical and emotional neglect; parental separation or divorce; exposure to domestic violence; parental substance abuse; parental mental illness; and incarceration of a relative. More recently, researchers have expanded these categories to include both additional individual and family-level factors (e.g., personal victimization, hunger, disturbances in family functioning, loss of a parent, challenging peer relationships, poor health) as well as the critical importance of ecological risk factors, including community violence, economic hardship, racial and other forms of discrimination, overemphasis on achievement, and stressful experiences within the school, child welfare, and juvenile justice systems (e.g., Wade, Shea, Rubin, & Wood, 2014). Collectively, this broader array more explicitly recognizes the role of macrosystemic structures, such as poverty and institutionalized racism (e.g., Spencer, 2007).

Although the original empirical work on ACEs was based on a predominately White, middle-class sample, demonstrating the pervasiveness of ACEs among that population (Felitti et al., 1998), recent research has employed more diverse samples (e.g., Bucci et al., 2016; Giovanelli, Reynolds, Mondi, & Ou, 2016). Although ACEs impact individuals from all socioeconomic backgrounds, growing up in poverty heightens children's risk for exposure to additional ACEs, as does belonging to a historically marginalized racial/ethnic group (e.g., Giovanelli et al., 2016; Slopen et al., 2016). At the same time, ecological risk factors that include and extend beyond poverty and institutionalized racism affect how children experience and respond to ACEs.

Impact of adversity on health

There is a strong, graded link between exposure to childhood adversity and risk of negative health, social, and emotional outcomes, including several major categories of chronic disease, lung cancer, various autoimmune diseases, depression and other mental illnesses, and high-risk behaviors (e.g., Felitti et al., 1998). These associations are mediated by the dysregulated stress response and its corresponding impact on immune system efficiency and brain architecture (e.g., Bucci et al., 2016; Walker, 2016). Specific physiological and neural processes implicated in these outcomes include the overproduction of inflammatory hormones, which underlies the relationship between childhood adversity and a range of chronic diseases (including obesity, asthma, hypertension, heart disease, and diabetes). In a similar way, damage to the ventral tegmental area (VTA), a dopamine pathway involved in motivation and reward that "numbs" sensitization to risk, has been shown to contribute to dramatic increases in risk-taking behaviors, such as substance abuse, smoking, and suicidal behavior (e.g., Brenhouse, Lukkes, & Andersen, 2013), as well as reductions in healthy self-modulation behaviors across socioeconomic groups (e.g., Luthar, Barkin, & Crossman, 2013). Collectively, these findings help to explain the heightened risk of premature mortality experienced by individuals with ACEs; on average, the life span of individuals with six or more ACEs is 20 years shorter than that of those with zero ACEs (Felitti et al., 1998).

Impact of adversity on learning

Chronic stress is associated with impairments in key brain centers, including the limbic system, through processes that are mediated and modulated by the HPA axis. The functioning of such brain regions is affected long before children start school and impacts key learning systems, including self-regulation, executive functions, attention, memory, stress reactivity, and language (e.g., Essex et al., 2011). These effects can be compounded by other risk factors, such as lower cognitive stimulation in the home and the absence of high-quality early childhood education, which collectively may significantly affect children's school and learning readiness (e.g., Center on the Developing Child, 2016).

As children get older, previous developmental challenges can accumulate and trigger a cascade of challenges to learning, both directly (through the previously described processes) and through negative exchanges with others at school (e.g., Blair & Diamond, 2008; Portilla, Ballard, Adler, Boyce, & Obradović, 2014). Children respond and adapt to these challenges in ways that vary both between children and within children across different settings, resulting in a continuum of behavior that ranges from reactive and/or impulsive at one end to proactive and/or goal-directed behavior at the other (e.g., Center on the Developing Child, 2016). Children's responses to chronic stress—including hypervigilance, defiance, and a compromised ability to regulate behavior—can affect how peers and teachers interact with them, further affecting learning readiness and cognitive engagement (e.g., Portilla et al., 2014). For example, young children who lack self-regulation are less likely to develop supportive relationships, engage in school, and pay attention in class, and they are more likely to withdraw and develop antisocial behavior as they grow older (e.g., S. F. Cole, Eisner, Gregory, & Ristuccia, 2013).

Chronic stress also is associated with chronic mental health conditions (e.g., mood syndromes, posttraumatic stress disorder, attention deficit hyperactivity disorder), which have replaced chronic physical illness in the top five most significant pediatric health issues affecting learning (e.g., Johnson, Riley, Granger, & Riis, 2013). Absent supportive relationships, new traumatic experiences may retraumatize children and result in school disengagement and failure (Bethell, Newacheck, Hawes, & Halfon, 2014). Overcoming the impact of adversity-related stress on learning requires both reducing sources of stress and strengthening capabilities in children and the adults caring for them.

Science of resilience

Scientists have long recognized the vital importance of understanding why some children do well under high-risk circumstances while others do not. Recent decades have witnessed four waves in resilience research: a first that was primarily descriptive, focused on key individual, relational, and environmental correlates; a second that sought to characterize the processes that bring about resilience; a third centered around its malleability, and related interventions to promote it; and a fourth—currently ongoing—that reflects revolutionary advances in developmental science and related technologies (Masten, 2007; Masten & Cicchetti, 2016). Such advances include novel methods for studying neurobiological and epigenetic processes, as well as new statistical models for analyzing change in individual children and identifying specific pathways for building capacity for resilience. In this way, with the support of dynamic systems mathematical methods and models, DST has come to provide a unifying, central model for the study of resilience (Lerner, 2006; Masten & Cicchetti, 2016; Overton, 2013; Von Bertalanffy, 1968; Zelazo, 2013).

A developmental systems perspective on resilience involves eight principles (Masten & Cicchetti, 2016): (a) human adaptation and development in continuous, multilevel coactions with the environment; (b) multiple interacting systems; (c) a capacity for adaptation conceptualized at multiple levels; (d) a capacity for adaptation in challenging circumstances involving multiple interacting systems; (e) manifestations of resilience reflecting both current and historical contexts; (f) self-organizing properties, including some that are not easily predictable; (g) dynamism (constant change and adaptation); and (h) a recognition that resilience is not a fixed trait that an individual categorically possesses or lacks, but rather it emerges through coaction with contextual, supportive, and relational factors.

Whether of a person, group, or larger system, resilience is best understood as a multilevel, biopsychosocial-ecological process wherein promotive internal and external systems integrate to facilitate the potential for positive outcomes (e.g., Masten & Obradović, 2006). In the context of individuals, it is defined as "the potential or manifested capacity of an individual to adapt successfully through multiple processes to challenges that threaten the function, survival, or positive development" (Masten & Cicchetti, 2016, p. 275). Importantly, resilience is not rare, but is rather a common phenomenon—there is an "ordinariness of resilience" (e.g., Bethell et al., 2014).

Equally importantly, resilience is not a trait. Biological and contextual resources contribute to early patterns of adaptation, which provide a foundation for—and thus predict—later, more complex patterns (Yates, Egeland, & Sroufe, 2003). And yet, adaptation is not a fixed process, and resilience is not immutable (e.g., Cicchetti, 2013). Throughout the lifespan, particularly during periods of transition, internal and external factors present new opportunities for adaptation or maladaptation (e.g., Ungar, Ghazinour, & Richter, 2013).

Consistent with the principles underlying the metaphor of the "developmental web," resilience is characterized by substantial heterogeneity (e.g., Bethell et al., 2014), dependence on contextual (e.g., social and cultural) supports, and equifinality (e.g., Masten, 2011). Children's long-term responses to adversities vary as a function of individual sensitivities and dispositions; socialization practices; the type, timing, and intensity of adversities; and the countervailing buffering supports available to them (e.g., Spencer, 2007; Spencer et al., 2015). Though exposure to risk is endemic to the human species, the nature of risk and the resources available to respond vary among cultural and ecological contexts (C. D. Lee, 2009), and no two individuals draw from the same combination and experience of these resources (Masten, 2014a). Moreover, notions of resilience are defined locally, and are culturally, socially, and historically embedded (Masten, 2011). The result is diverse pathways that lead to different, but equally viable and complex, development and well: being—equifinality.

Such heterogeneity and variability have important implications for future resilience research, highlighting the value of multilevel, person-centered approaches and within-group, within-gender analyses (e.g., Coll & Marks, 2011; Luthar, Crossman, & Small, 2015). Although productive, research focused on linear models and indices of cumulative risks (e.g., the ACES survey) and assets can mask the salience of individual experiences and multiple, intersecting factors. Meanwhile, a dynamic systems approach has the potential to reveal factors and combinations of factors that account for variability in adaptive responses. For example, nonlinear models (e.g., Garmezy, Masten, & Tellegen, 1984; Masten et al., 1988) suggest that individual experiences and outcomes result from both stress dosage and the quality of the recovery environment.

Two key concepts are involved in making inferences about resilience—risk/vulnerability criteria (discussed more thoroughly in the previous section on stress and adversity) and positive adaptation criteria (e.g., Luthar et al., 2015; Masten, 2014a). Within both sets of criteria, the idea is not that a given factor always functions as a negative or promotive/protective moderator, but rather that multiple factors coact in a given context to produce specific sets of outcomes. Differential sensitivities to experience, including both risk and adaptive factors, play an important role (Masten, Best, & Garmezy, 1990; Rutter, 1987), as do ecological factors that avert, moderate, and/or buffer the consequences of risks (Spencer, 2007; Spencer et al., 2015).

While resilience is not fixed, resilience theory can highlight positive pathways of adaptation through time. Achievements in core developmental tasks in one developmental period can engender positive developmental cascades, setting the stage for future competence (e.g., Masten & Coatsworth, 1998; Stafford-Brizard, 2015). In addition, when young people at high levels of risk are supported by strategic prevention or intervention efforts, these efforts can forestall negative adaptation (Masten & Cicchetti, 2010). Specific adaptive pathway models include periods of stress resistance, breakdown, recovery, and normalization (Masten & Reed, 2002). One of the most intriguing pathways involves improvement in adaptive functioning following exposure to catastrophes, particularly acute catastrophes, suggesting an initial breakdown followed by processes of reorganization and strengthening (Calhoun & Tedeschi, 2006). Research in this area reinforces the concept—one that has a long history in resilience science—that some exposure to adversity may be better than none (Masten, 2012; Rutter, 1987). At the same time, even in the context of adaptive functioning, the cumulative allostatic load associated with chronically harsh environments can exhaust adaptive resources and present significant, long-term consequences to health and well-being, with much individual variation as a function of personal attributes and environmental supports (e.g., Juster, McEwen, & Lupien, 2010; McEwen, 1998; Miller, Yu, Chen, & Brody, 2015).

Positive adaptation can be found at multiple system levels (e.g., Cicchetti, 2010). Promotive and protective processes shown to predict variations in adaptation include adaptive molecular genetic (e.g., Caspi et al., 2002) and neurobiological systems, such as the learning systems of the brain, the stress response systems, and the self-regulatory systems, as well as the integration of these systems (e.g., Masten & Obradović, 2006). Commonly implicated psychological factors (Masten & Cicchetti, 2016) include emotional security, attachment, and stable, responsive relationships (Luthar, 2006; Masten, 2014a); mastery motivation and self-efficacy (e.g., Ryan & Deci, 2000); cognitive development and problem solving (e.g., Losel & Farrington, 2012); self-regulation and executive function (e.g., Zelazo & Carlson, 2012); meaning making (Frankl, 1959; McLean & Pratt, 2006; Park, 2010); and positive perspectives on the self and future (e.g., Kirschman, Johnson, Bender, & Roberts, 2009). Broader contextual factors (Masten & Cicchetti, 2016) include family systems (e.g., Walsh, 2016), schools (e.g., Masten, 2014b), social and peer networks (e.g., Losel & Farrington, 2012), and cultural systems (e.g., Ungar, 2012).

Supportive relationships are particularly important. Research has repeatedly found that children who do well in the face of adversity have at least one stable and responsive relationship with a parent, caregiver, or other adult (Center on the Developing Child, 2016). In one recent example, Brody, Miller, Yu, Beach, and Chen (2016) found that supportive family environments in adolescence can serve as a protective buffer to racial discrimination and its effects on premature biological weathering. This specific finding—and the larger pattern within which it fits—highlights the profound role of intergenerational processes (further analyzed in the companion article), and has led resilience researchers to recommend policies and programs to better support the adults in children's lives (Luthar, 2015).

Conclusion

This article identifies a convergence of multiple sciences around core principles of human development, situating and integrating such principles within a dynamic, holistic developmental systems framework that enables a deeper understanding of the whole child in context. Such principles include the fundamental role of neural malleability and plasticity; the interconnectedness of individuals with their social, cultural, and physical contexts through complex, dynamic coactions over time; the role of genes as followers, rather than drivers, in progressive developmental processes; the integration of cognitive, social, emotional, and affective processes in constructive skill development and learning; the pervasive reality of human variability, and profound importance of its study; the stability in patterns of complex skills that emerge across development; and the dynamics of adversity and resilience.

Collectively, these principles give rise to an important opportunity to facilitate the design and personalization of child-serving settings such that they are developmentally constructive, interpersonally rich, and attuned to children's individual capacities, needs, and potential. Specifically, in schools, when consideration is given to the key drivers of positive developmental and learning outcomes—including attuned relational supports; buffering of stress; intentional, sequenced development of integrated habits, skills, and mindsets; rigorous, mastery-oriented pedagogy; and culturally responsive instructional and curricular design—the developmental range, performance, success, and, ultimately, potential of *all* children can be optimized.

Our companion article, *Drivers of Human Development,* builds upon this convergence of research and knowledge, providing an in-depth exploration of the ways in which nested micro- and macro-contextual factors affect children's development across the life span.

Acknowledgments

We thank our partners in this work: The Opportunity Institute, The Learning Policy Institute, and EducationCounsel. We also thank the following individuals for contributions to this article: J. Lawrence Aber, Arvin Bhana, Natacha Blain, Mette Böll, Marc Brackett, Catherine Brown, Nadine Burke Harris, Michele Cahill, Annemaree Carroll, Dante Cicchetti, Sarah Caverly, Micheline Chi, Greg Chung, Richard Clark, Patrick Cushen, Adele Diamond, Carol Dweck, Lisa Dickinson, Celene Domitrovich, Angela Duckworth, Helen Duffy, Camille Farrington, Ron Ferguson, Ellen Galinsky, Adam Gamoran, Robyn Gillies, Catherine Good, Mark Greenberg, Donna Harris-Aikens, Stephanie Jones, Paul LeBlanc, Carol Lee, Patricia Kuhl, Gloria Ladson-Billings, Felice Levine, Suniya Luthar, Jeannette Mancilla-Martinez, Ann Masten, Deborah Moroney, Elizabeth Nolan, Pedro Noguera, Edmund Oropez, Daphna Oyserman, Kent Pekel, Jim Pellegrino, Karen Pittman, Lisa Quay, Cynthia Robinson-Rivers, David Rose, Pankaj Sah, Bror Saxberg, Robert Selman, Peter Senge, Jim Shelton, Russ Shilling, Jack Shonkoff, Dan Siegel, Arietta Slade, Deborah Smolover, Brooke Stafford-Brizard, Laurence Steinberg, Jim Stigler, Diane Tavenner, Jessica Tsang, Melina Uncapher, Sheila Walker, Greg Walton, Roger Weissberg, Martin West, David Yeager, and Philip Zelazo.

Funding

This project was supported by grants awarded by the Chan Zuckerberg Initiative, Raikes Foundation, Ford Foundation, and the Bill and Melinda Gates Foundation.

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