CHAPTER 40

BEYOND TRAIT THEORY ACCOUNTS OF GIFTEDNESS

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Gifted education exists at the intersection of psychology and education. The roots of gifted education are deeply intertwined with the roots of psychological science (Robinson & Jolly, 2014). Psychology is one of the most wide-ranging of the scientific fields, and it contains numerous perspectives, foci, and philosophical orientations. We speak not of the traditional division of psychology into its recognizable subfields (e.g., clinical, developmental, cognitive, biological, etc.), but rather we note those perspectives and orientations that cut across subdisciplines, providing unified worldviews through which phenomena are understood. One of those dominant perspectives is known as trait theory. This perspective explains individual differences in behavior or performance in terms of differences in underlying traits, which are components shared by all individuals but whose strength or quantity varies between individuals (Elkind, 1981), exemplified by the psychometric approach to studying human intelligence (cf. Carroll, 1993), as well as personality psychology from Allport (1937) to the present.

We summarize the trait theory perspective as follows: Individuals are collections of traits—general intelligence (*g*), Big Five personality components (e.g., extraversion and openness), grit, narcissism, aggression, mindfulness, and so on. These traits exist as latent variables and can be measured using carefully designed and validated psychological or educational instruments. Typically, there is no intrinsically meaningful metric for measuring these traits, so they are often expressed on a norm-referenced basis.

These traits are relatively stable over time, though this stability varies considerably according to the nature of the trait. For example, conscientiousness (a Big Five personality component) is more stable than depression (a psychological condition that is responsive to stress, medication, and treatment). Individuals vary widely in their endowment with respect to these traits. The quantity of each trait possessed by individuals results in observable differences in behavior and performance that are relatively stable across contexts.

Gifted education is rooted in this perspective, which has been fruitful, led to many important discoveries, and provided the underlying rationale for a large portion of the interventionist wing of psychology. However, like all perspectives, the focus on traits has significant limitations and "blind spots." In this chapter, we argue that moving beyond this perspective is necessary for our field to make continued progress with respect to its scientific agenda—understanding the nature of precocious intellectual talent in childhood and exceptional achievement in adulthood.

The trait theory perspective explains the behaviors and performances associated with giftedness in terms of underlying differences in key traits, such as g. For example, when a 4-year-old is able to read at a third grade level, the individual differences explanation might proceed as follows:

1. The child is endowed with supernormal *g*. He or she may also have high levels of facilitative personality traits, such as curiosity and grit.

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2. This endowment resulted in the rapid development of reading ability, which is also a trait.

Therefore an informal summary of the explanation for the observable behavior of a 4-year-old reading well above a normative level given his or her age is to appeal to the child's endowment with respect to traits. Why can he or she read at such an advanced level? Because he or she is gifted. In other words, because he or she is more intelligent than most of his or her age peers.

This worldview is supported, or at least appears to be supported, by extensive evidence. This evidence stretches back to the earliest days of the development of intelligence tests and was formalized in the discipline of factor analysis, in its exploratory and confirmatory guises. *Factor analysis* is a mathematical and statistical technique that is extensively used in instrument development. Starting with the assumption that *latent variables* (i.e., dimensions or traits) exist but cannot be directly measured, factor analysis is used to discover the number and nature of latent variables that are presumed to cause correlations between items, tasks, or scores.

There can be little doubt that young children who exhibit exceptional academic performance or who acquire complex reasoning skills years before their peers are intelligent using any reasonable definition of the word. Although true, the trait theory explanation for this phenomenon is certainly incomplete, perhaps even tautological. It is troubling, perhaps, when what is taken as the evidence for the existence of a particular trait, such as intelligence, is also considered to be an indicator that measures the quantity or intensity of that trait. Returning to the previous example, how do we know that the 4-year-old child is highly intelligent? Because he or she has mastered skills beyond his or her age or grade level. Why has he or she mastered that skill? Because he or she is highly intelligent. Appealing to differences in intelligence as an explanation of outstanding problem-solving performance explains nothing, because the way intelligence is quantified is by measuring how effectively individuals can solve problems.

The trait of *g*, is presumed to be the cause of the so-called *positive manifold* (van der Maas, Kan, & Borsboom, 2014)—the finding that performance on many disparate mental tasks are correlated with one another. Trait theory holds that the cause of these correlations between tasks is that they are all expressions of a common trait of *g*. Higher levels of *g* cause superior performances on a variety of cognitive tasks, and the fact that these have a common cause explains the positive manifold. However, there is an alternative explanation of the positive manifold that agrees just as strongly, or in some ways stronger, with the data and does not posit the true existence of a trait called *g* (e.g., van der Maas et al., 2006).

The fact that the trait theory explanation for intelligence feels satisfying to many people is reminiscent of the way nonexperts tend to respond to neuroimaging study results that localize certain behaviors or processes to certain regions or structures of the brain. For example, learning that facial recognition seems to occur in the fusiform gyrus (Kanwisher, McDermott, & Chun, 1997) does not explain how facial recognition works—only that facial recognition will be affected if the associated structure is damaged. At best, these types of localization findings are the preliminary, incremental discoveries that can ultimately contribute to the discovery and validation of proper theoretical accounts of facial recognition. They in no way represent complete explanations, and the same can be said for trait theory accounts of behavior. Discovering that individuals differ in their ability to reason, master skills, and solve problems because they vary in intelligence is merely a first step down a long road toward understanding these phenomena.

This chapter describes attempts to understand giftedness or intelligence that go beyond the trait theory perspective. The considered perspectives augment trait theory accounts by devoting attention to the issues that have been ignored or deemphasized, which notably include the underlying processes or behaviors, and their development. These processes, in turn, give rise to skill acquisition, problem solving performance, and creative productivity that are the *sine qua non* of giftedness.

RELEVANT THEORY AND PRINCIPLES

Cognitive psychology began as a reaction against the behaviorist insistence that understanding the "black box" (i.e., the functional mechanisms of cognition and behavior) was unnecessary. Therefore, cognitive theorists have emphasized accounts of reasoning that feature functional units. Modern cognitive theory focuses on three core components: executive function, attention, and working memory. Although these units may be considered in isolation, they function as an integrated system, and it is essential to appreciate the interactions and interdependencies between these components (Styles, 2005). Specific models vary in terms of whether working memory or executive function is superordinate; such details are beyond the scope of this chapter.

Executive Function

Executive function provides the management and control of cognitive processes (Alvarez & Emory, 2006). It is involved in the planning, monitoring, and execution of tasks, as well as in directing attention. The executive function system is involved when novel, nonrehearsed (i.e., nonautomatized) tasks are performed (Gilbert & Burgess, 2008). In fact, executive function is particularly involved when automatized responses must be suppressed. A classic task for measuring selective attention, which is thought to be a major role of executive function, is the Stroop test (Jensen & Rohwer, 1966). In the Stroop test, individuals are presented with the names of colors where the color of the text is dissimilar from the text itself. For example, the word *red* may be presented in blue text. Individuals are instructed to ignore the text and simply report the color of the letters. This is difficult because of the interference that is created because of the automatic reading of the text. The executive function system is heavily involved in suppressing this automated reaction and selecting the correct response.

Attention

Human beings are bombarded with stimuli in every moment of their lives. The quantity of information gathered by our senses, and self-generated in our minds, vastly outstrips our processing capacity. *Attention* is posited as the selection mechanism through which information enters consciousness. It is often considered to be a component of working memory and is under the volitional control of the executive function system (Stipek & Valentino, 2015). It has a relatively limited capacity, and the amount available varies across situations and levels of arousal (Jensen & Rohwer, 1966).

Working Memory

Working memory is a system that briefly stores and processes information (Baddeley & Hitch, 1974; Logie & Cowan, 2015). It is involved in reasoning, comprehension, and memory formation. Working memory is conceptually distinct from the related concept of short-term memory (STM) because STM is a passive system involved only in storage, whereas working memory involves active manipulation and organization in addition to storage. Furthermore, working memory also should be distinguished from long-term memory (LTM). Working memory capacity is extremely limited, with the contents subject to rapid decay. In comparison, LTM is vast and permanent but is not usable for online processing.

Classically, adult working memory capacity was thought to be seven plus or minus two items (Miller, 1956). Contemporary estimates are lower, with Cowan (2005) suggesting four plus or minus one item. Interestingly, the items or contents to be stored in working memory can be compressed into larger units known as *chunks*, which can serve to dramatically increase the effective capacity of working memory. This is because each "slot" of working memory can contain a chunk rather than a single datum. As will be discussed later in this chapter, effective chunking is one means by which expert performance is achieved.

Cognitive Theories and Giftedness

A substantial amount of evidence in the literature on giftedness supports cognitive accounts of giftedness. Measures of executive function are substantially correlated with measures of fluid intelligence (Davis, Pierson, & Finch, 2011). Gifted children appear to differ from their typical peers with respect to working memory capacity, strategy use and selection, and metacognition. Working memory has been found to have moderate to high correlations with measures of *g* (Fugate, Zentall, & Gentry, 2013; Murray & Byrne, 2005; Paulewicz, Chuderski, & Nęcka, 2007; Unsworth, Spillers, & Brewer, 2009). Cho and Ahn (2003) compared strategy use between gifted and nongifted children on a five-session recall task. Although recall strategies were explicitly taught during the third session, the gifted children in the sample had spontaneously generated the most effective learning strategy without instruction.

Several studies have demonstrated that gifted children possess superior declarative knowledge of problem-solving procedures and are more likely to recall and adapt strategies that have successfully worked in the past (Carr, Alexander, & Schwanenflugel, 1996; Jaušovec, 1991; Montague, 1991). Gifted children are quick to acquire new strategies (Scruggs & Mastropieri, 1988), and they are more flexible in strategy use during problem solving, which allows them to abandon nonfruitful strategies in favor of more effective ones (Jaušovec, 1991; Kanevsky, 1990).

Steiner's (2006) microgenetic analysis of strategy use by gifted children highlights the advantages of strategy selection and metacognitive monitoring that facilitate their advanced ability to solve problems. In this study, a sample of gifted and nongifted second graders played a computer game ("Space Race") in which they were asked to predict which of two competing rockets would win in a race. The rockets differed on dimensions such as shape, color, and number of wings, and these dimensions were associated with the rocket's speed. Steiner identified four levels of strategy that could be used to make the prediction: ranging from no discernable strategy to controlled experiments to isolate the effect of each feature. Interestingly, she found that the gifted and nongifted groups used all four levels of strategy across the 15 trials. The gifted students were much more likely to spontaneously acquire and use controlled experiments, the most effective strategy, but they did not abandon less effective strategies after discovering more effective one. The less effective strategies continued to persist—a finding that will be discussed further in this chapter. Also, it is important to note that the studies reviewed in this section operationalized the word *gifted* differently. For example, the gifted students in Steiner's (2006) study were defined in accordance with Georgia's law-mandated multiple criteria identification system. Other studies considered here defined giftedness by high IQ (Kanevsky, 1990) or by high IQ or high achievement (Carr et al., 1996). These varying definitions make it difficult to make confident generalizations across studies.

Contrasting Cognitive Theories With Trait Theories

It is interesting to consider how the cognitive model differs from trait theory. At first, it may appear that the overarching trait of *g* has simply been replaced with the traits of attention, working memory, and executive function, but this is simply not the case. Although it is true that these three cognitive components represent dimensions of individual differences (i.e., people can and do vary with respect to their ability to switch, direct, and maintain attention; their capacity of working memory; and their effectiveness of executive function), these differ from the way traits are typically considered in some important ways.

The cognitive model avoids the circularity problem described previously, because the observed behaviors deemed to be the results of these components' operation are not isomorphic with the behaviors deemed to measure the degree of an individual's endowment with respect to these components. The cognitive model specifies specific tasks as being immediate, proximal, or relatively pure measures of the functioning of individual components, whereas performance on other tasks are viewed as being distal effects of these components. In the *g* trait theory, there is no way to measure intelligence other than by measuring performance on a set of tasks (e.g., vocabulary, block design) thought to result from intelligence. In cognitive theory, although it is clear that compromise to executive function, attention, or working memory can impair performance on problem-solving, learning, or other tasks, the performance of these components can be measured independently of performance on the tasks themselves. For example, working memory capacity can be measured directly via digit span or related tasks. The consequences of poor working memory can be detected on a variety of problem-solving or learning tasks. Executive function can be measured via the Stroop task, but insufficient executive function reduces performance on any task that requires planning, coordination, and monitoring of mental effort.

Executive function, attention, and working memory are dissimilar to traits because they are viewed as active functional devices rather than passive structures. Working memory is not a trait; it is a specific machinery that enables the storage and processing of information. It does not create behavior by its mere existence; it creates behavior via its functional activities.

From the cognitive perspective, it seems clear that intelligence is a kind of unitary shorthand term that represents the degree to which the cognitive components function effectively. It can be thought of as a global descriptor of the functional effectiveness of the cognitive system. A highly intelligent child—a child who is able to master content and skills or to effectively solve problems that are typically out of reach for his or her age peers—is a child whose cognitive components function with a high degree of effectiveness, integration, and efficiency. If the child's executive function is especially well-developed, he or she will be able to direct, switch, and maintain attention to a very high degree, thereby ensuring that effort can be sustained as long as necessary. The child will able to select, evaluate, and change strategies as needed when solving problems. If the child's working memory capacity is large, additional bandwidth is available for storing, encoding, and manipulating information. When excess capacity remains after encoding a problem, these resources can be devoted to metacognitive monitoring or other activities that facilitate problem-solving effectiveness.

Despite our discussion of the differences between the cognitive perspective and the trait theory perspective, we must recognize that there are substantial similarities. Whereas the trait theory perspective accounts for precocious problem-solving ability or skill acquisition in terms of a unitary trait called *g*, the cognitive perspective appeals to executive function, attention, and working memory. And despite the distinction between passive structures and functional machinery, the general structure of the trait theory and cognitive arguments end up appearing pretty similar. Why are some kindergarteners able to read at a third-grade level? Because they are superior to their age peers with respect to the executive function, attention, and working memory. Therefore, we view the cognitive perspective as broadly similar to the trait theory perspective—a kind of hybrid orientation—that makes important extensions to the trait perspective by seeking to describe the machinery inside the "black box." We view this contribution as critical because it provides an escape from circular logic.

Imagine a mechanic investigating why some cars can accelerate more rapidly than others. A trait theory approach would involve testing each car on a dynamometer, measuring its horsepower and torque. The resulting explanation for the variance in acceleration might therefore be that some cars are faster than others because some have more horsepower. However, this is not an explanation for variance in acceleration, because acceleration is a direct consequence of horsepower. Circular logic strikes again. In much the same way, explaining why some children can solve amazingly difficult problems by assigning to them a number (IQ), which is based on the number of difficult problems they can correctly solve, does not explain why they can solve difficult problems. A cognitive approach would involve disassembling the engines of the cars and noting that some have more cylinders, some have larger engines, some have direct injection, and some have turbochargers. Some cars are faster than other cars because their engines vary in their design, and these design differences result in varying degrees of horsepower.

EXPERTISE DEVELOPMENT

The expertise development paradigm explains the origin and development of individual differences in performance in terms of psychological processes that occur because of repeated exposure to a discipline and practice of skills. The goal of the psychological study of expertise development is to explain how individuals progress from being low-skilled novices to becoming experts capable of daunting levels of performance. The expertise development literature has generally appealed to the cognitive worldview and discusses expert performance largely in terms of changes in memory, as well as automatized execution of practiced tasks.

Domain-Specific Memory Performance

Two of the most famous studies in psychology are de Groot's (1965) and Chase and Simon's (1973) classic studies of chess players at various levels of skill. de Groot compared novice and master chess players on different aspects of their thought process and found that there were many similarities. As Chase and Simon put it, "de Groot was unable to find any gross differences in the statistics of their thought processes" (p. 55), which was considered surprising. For example, the master players did not consider more moves than the novices. However, one important difference did emerge that clearly distinguished novices from experts. When given a few seconds to examine a chessboard on which the pieces were arranged according to a master game, de Groot found that his grandmaster participant could reconstruct the positions of the pieces from memory with almost 100% accuracy, whereas de Groot's least-accomplished subject could only achieve about 50% accuracy. It seemed that some aspect of expert chess performance involved heroic memory recall. However, when the pieces were arranged randomly on the board, in positions that would not arise during the normal course of play, the expert chess players' recall was just as poor as the novices' recall, subject to the usual constraints of working memory capacity. It was not that a generalized ability for exceptional recall caused some players to achieve mastery, but players seemed to develop this memory because of practice and expertise. In fact, these studies provided some of the first evidence of chunking, because if masters did not have increased general memory capacity, then it must be that they can store more information in each slot. Chess masters are more effective than chess novices, wrote Chase and Simon, because of "an extensive cognitive apparatus amassed through years of constant practice" (p. 56). For the experts, years of intensive effort in chess have resulted in the storage of many positions, patterns, and orientations of chess pieces, organized meaningfully by their strategic merits. Where a novice might attempt to recall the positions of numerous pawns on the board, the expert may perceive a pawn chain configured to resist assault and to block certain lines of attack. The novice perceives a semi-random scattering of pieces; the expert recognizes a subtle variant of the King's Gambit opening.

The memory advantages conferred by expertise may be too extensive to be explained via increased chunk capacity. Ericsson and Kintsch (1995) proposed a new domain-specific form of memory that they called *long-term working memory* (LT-WM), which only becomes operational after extensive practice or training. LT-WM is similar to working memory in that it is used to store and process immediate information during task execution. The information itself is stored in LTM, but the retrieval cues needed to recall it are stored in ordinary working memory and are thereby subject to rapid decay unless periodically refreshed. The use of LT-WM allows experts to expand their effective working memory capacity tenfold as compared to nonexperts (Ericsson & Kintsch, 1995), but only in the domain of their expertise. In the chess example, the expert chess player need not recall the locations of many individual pieces but simply needs to encode the retrieval cues that activate specific patterns already committed to LTM (Ericsson & Delaney, 1999). Instead of memorizing the locations of all the individual pieces, the chess master need only recall that the pieces are arranged according to the King's Gambit. Outside of the domain of expertise, these extensive schemas are absent. Rather than storing references to already learned material, the working memory system must attempt to store all the relevant details directly. The small capacity of the working memory system is quickly overwhelmed, and novice performance results. We point out that the LT-WM theory has been challenged and refer readers to Gobet (2000) and Postal (2004) for further reading.

Automaticity

In the initial stages of skill acquisition, a great deal of conscious effort is required, with deliberate attention devoted to each step. In this initial period, the ability of the executive function system to coordinate, manage, and monitor tasks, and the rather severe limitations of working memory are major performance bottlenecks. After practice, skills become automatized and can be executed with little effort. Schneider and Shiffrin (1977) proposed a dual-mode theory of cognition composed of controlled processing and automated processing. Controlled processing is performed under conscious control. It is serial in nature, requires deliberate attention, and is performance limited because of working memory constraints. By contrast, automated processing is parallel and largely effortless. Attention is minimally required, and working memory involvement is reduced or eliminated. This frees up resources that can be applied to other processes, including "big picture," macrolevel considerations. One example of automaticity in action is reading (LaBerge & Samuels, 1974). In the early stages of literacy development, young children slowly examine letters one by one, attempting to identify them and to recall their sounds. Letters slowly, haltingly become assembled into words, and words into sentences. Comprehension is difficult, however, because the effort required of simply decoding the letter sounds and assembling them into words is so demanding of resources that none are available to devote to the macrolevel issues of narrative, plot, and meaning. Deficits in automaticity are frequently implicated in reading disorders and other learning disorders (Wertlieb, 1990).

Bargh (1994) described four primary aspects of automatic processes. First, when executing automatized processes, individuals may not have awareness of their actions. For example, skilled drivers are often not aware of the frequent small steering corrections required to maintain a desired track. Accomplished guitarists may not be aware of the exact movements of their fingers required to play chord sequences. Second, automatic processes are initiated automatically, without intentional activation. Third, they are executed efficiently, meaning that their execution consumes minimal cognitive resources. And fourth, they may be difficult to control, alter, or interrupt prior to completion.

The role of executive function transforms after automaticity has been achieved. Rather than being involved with sequentially executing each step of the process, as in the early stages of skill acquisition, in later stages, executive function takes on a monitoring role. Indeed, the primary job of executive function once skills are automatized is to determine when to cease automatic processing and return to controlled, effortful processing. This would be required when, for instance, an unusual situation is encountered that does not conform to the automatized process.

The Role of Talent in the Expertise Development Paradigm

Although elite performance is often explained in terms of exceptional abilities, in the popular imagination, the role of preexisting differences in innate general abilities is not emphasized in the expertise development literature. The role of talent is greatly diminished, perhaps even eliminated. Instead, the focus of investigation is on the adaptations that occur because of long-term deliberate practice of a skill. These adaptations include not only the changes in memory and automatization previously discussed, but also anatomical changes in the body and brain (Ericsson & Charness, 1994). The extreme abilities of savants and prodigies would seem to contradict the diminished role of talent in the expertise development perspective. However, Ericsson and Charness (1994) argued that a close examination of the evidence reveals training experiences or practice that had previously been ignored. For example, they referenced studies of musicians with "perfect pitch," pointing out that the musicians with perfect pitch in Tekeuechi and Hulse's (1993) study had musical training starting no later than six years old. Rather than reflecting innate talent, perfect pitch may be a consequence of musical instruction during a critical period during early childhood. Whereas laypersons are apt to attribute outstanding performance to innate talent, the expertise development perspective attributes performance to the cognitive changes that accompany deliberate, sustained practice or training in a domain.

Contrasting Expertise Development With Trait Theories

The expertise development account of advanced performance is, in many ways, the opposite of the trait theory explanation. Trait theory proposes the existence of an innate, domain-general trait called *g* that creates the positive manifold through its nature as a primary causal agent of many types of cognitive performance. By contrast, expertise development theory is exceptionally domain-specific and almost completely discounts any role of innate intelligence (or talent) in determining performance. According to trait theory, observed performance differences can always be resolved into differential exposure to instruction and deliberate practice, as well as the quality of the practice. It is unclear how the expertise development theory could explain the positive manifold—the positive correlations observed between performances on many disparate tasks—because expertise does not transfer across domains. And yet the existence of the positive manifold is an undisputable feature of human psychology.

Sternberg's (1985) triarchic theory of intelligence provides some insight that can help integrate the expertise development perspective with perspectives that view performance largely in terms of innate abilities. The experiential subtheory of Sternberg's model speaks to individual differences between the automatic processing of a familiar, practiced routine and the controlled processing required when an individual encounters a novel situation. Sternberg defines intelligence as how effectively individuals can cope with novelty. Because novel situations require controlled processing, and controlled processing necessarily involves a heavy overhead with respect to executive function, attention, and working memory, individual differences in the functional characteristics of these components will create individual differences in performance in novel situations. However, intelligence also brings advantages in automated performance. Highly intelligent individuals achieve effective automation more rapidly, require less practice, and automate more completely. All of which results in performance that increases more rapidly per unit of time (or per unit of exposure, training, or practice), allowing more highly intelligent individuals to achieve high levels of performance more quickly than others.

Expertise Development and Giftedness

In gifted education, the talent development paradigm (Dai & Chen, 2013) represents a fusion of the traditional trait-centered model of giftedness and the expertise development perspective. The talent development perspective is explicitly developmental (Jarvin & Subotnik, 2015). It is more concerned with significant adult accomplishment than childhood precocity (see Chapters 15 and 17, this handbook). The talent development perspective views individual differences in performance at the very early stages of skill acquisition to be a consequence of variation in underlying innate ability. From this perspective, innate ability is a signal of the potential for advanced achievement, but is not intrinsically interesting, because achievement is what matters. Ability is converted into meaningful contributions to the culture through a long, intense process of intensive skill development, practice, and competition. The degree to which individuals are willing and able to engage in this process depends on their motivation and other psychosocial factors (e.g., perseverance), the availability of appropriate training opportunities and mentors, and the degree of psychosocial support (Subotnik, Olszewski-Kubilius, & Worrell, 2011). Readers are referred to Kaufman's (2014) discussion of a framework for integrating the expertise development and trait theory paradigms.

DYNAMICAL SYSTEMS

Dynamical systems theories explain how complex phenomena emerge out of the interactions between low-level units. Even when the behavior of the low-level units is simple and perfectly predictable, the emergent high-level behaviors can be extremely complex or even chaotic—which means although the gross pattern of behaviors may be generally predictable, the specific behaviors are random or quasi-random (Wolfram, 2002). The conditions that lead to the development of a superior state of intelligence may be best conceptualized using a nonlinear dynamic systems model. Thelen and Smith (1994) theorized dynamic systems as a nonlinear explanation of behavior, in that a behavior does not develop in a rigid stage-like process, but instead arises out of the complex interaction of variables in a particular context.

One important aspect of dynamic systems is that they can spontaneously self-organize or construct inputs from variables in an environment, and are therefore influenced by specified conditions within the system and by the environment in which they operate. The inputs change over time and are mutually shaped, which can increase or decrease variability and gives rise to fluctuations or stability within the system. Inputs inform the system in real-time and the characteristics of a system are dependent on the level of inputs from the current environmental or social context. The system unfolds over time, with any current state dependent on all previous states or the history of the system (Alligood, Sauer, & Yorke, 1997).

Given the right conditions, the system can form an attractor state. An attractor state is achieved when a system minimizes entropy, meaning its use of energy is most efficient at a certain level of input from each parameter; this appears to an outside observer as an emergent behavior, mental structure, or mental process. Stable attractors appear as behaviors with little variability and they are resistant to perturbations. Some behaviors that appear random may actually be chaotic. Chaotic systems are extraordinarily sensitive to initial conditions. Although completely deterministic, they appear random because of this sensitivity.

The dynamic systems perspective may yield insight into Steiner's (2006) results from the "Space Race" study previously described. Steiner found that the gifted and average-ability children used low-level and high-level strategies; however, they differed in the patterns of strategy use. We might (speculatively) infer that some children have stabilized attractor states that allow them to quickly identify, acquire, and continue to use higher level strategies. Over subsequent trials, the gifted students were drawn to high-level strategies and used low-level strategies less than their peers.

The average-ability children did not seem to rely on any particular strategy during problem solving. Instead, they danced between high-level and low-level strategies with no noticeable pattern. Using dynamic systems, we could argue this process is not random, in that the progression from each type of strategy used was dependent on context and variable inputs at the start of each trial. These processes could be described as chaotic, as they are not "attracted" to any particular type of strategy.

There is some evidence to support our speculation that average-ability children have chaotic attractor states. For example, Jaušovec (1998) found that gifted children use less brain activity when solving problems. When children were resting (i.e., not solving problems), there were no differences in brain activity between gifted and average-ability children. However, average-ability children used more mental energy when solving problems that used working memory, deductive reasoning, and arithmetic. Further studies support a relationship between higher intelligence and use of brain activity when performing various problem-solving tasks (Haier, Siegel, Tang, Abel, & Buchsbaum, 1992; Jaušovec, 1996; Neubauer & Fink, 2003).

Reinterpreting these findings from a dynamical systems perspective could mean that the strategic system of gifted children has minimized entropy, allowing for more stable mental processes. These same processes are chaotic in average-ability children as they jump from one strategy to another. This lack of stability requires a higher level of mental activity. Gifted children activate task-specific areas of the brain relevant to solve problems, whereas average-ability children activate areas of the brain irrelevant to solving the problem at hand (Jaušovec, 1996). Indeed, average-ability children demonstrated greater brain activity, or more mental effort, that lead to wasted energy, which may be the result of chaotic processes related to solving problems.

Intelligence and Snowflakes

Although intelligence doesn't have a lot in common with snowflakes, Dai and Renzulli (2008) suggested they have at least one thing in common: they are dynamic systems that self-assemble and self-organize. Dai and Renzulli focused on the development of behaviors that leads to superior ability or talent. They insisted that intelligence is a complex, open living system with functional, developmental, and temporal dimensions (see Chapter 1, this handbook).

The functional dimension comprises the individual and his or her interaction with the environment as an important influence on intelligence. This person–environment relationship is viewed as an "open, self-directed, adaptive system, constantly exchanging energy and information with its environment, [and] capable of changing itself as well as its environment" (Dai & Renzulli, 2008, p. 115). This intersects with the developmental dimension, where gene expression and biology unfold. Our genes also interact with the environment, during physical development and adapting conditions to which we are exposed. Finally, the functional and developmental dimensions unfold across a temporal dimension. Dynamic systems must evolve over time, accruing a history that forever becomes part of the system.

Dai and Renzulli (2008) stipulated three underlying facets that mark giftedness using dynamical systems. First, *selective affinity* is the development of a strong interest within an individual. It can be thought of as the "seeking system" within the brain and it often rises early in childhood. There is speculation as to whether this behavior is guided by interferences (e.g., from a parent or caregiver), but an interest in an activity is often observed that is described as nearly obsessive (Feldman, 1986). Positive feedback on task-related behaviors further strengthens selective affinity, leading to a precocious understanding within a specific domain (Renzulli, 2002).

Second, *maximal grip* is the tendency of an individual to master knowledge within a domain. A more deliberate act than selective affinity, maximal grip requires a high level of motivation, self-efficacy, and the acquisition of skills. It also requires access to the best resources within the domain to be mastered. Third, to be at the edge of chaos is to be on the edge of innovation. It requires a level of mastery within a domain of knowledge that must be balanced with what is unknown, or what could be, to incite creativity. Chaos may feel to the person experiencing it as if their mind is jumping around from one idea to another in a seemingly random manner. The interaction of these facets of intelligence—selective affinity, maximal grip, and being at the edge of chaos—leads to unique temporal trajectories that account for individual differences in achievement.

Reassessing the Positive Manifold

It is commonly accepted by trait theorists that the latent factor of *g* exists and is responsible for the positive manifold. Van der Maas and colleagues (2006) applied dynamical systems theory to the study of intelligence. They described how the positive manifold could arise from the mutual interactions of many independent cognitive units. They simulated the development of such units over time using a set of coupled differential equations, similar in form to the predator–prey models seen in computational biology. Their model resulted in the emergence of a positive manifold that would have created an apparent dominant general factor via factor analysis, in spite of the fact that no such entity existed. Interestingly their model reproduced results consistent with many other peculiarities of observed psychometric test data, including the Flynn effect and differential heritability of intelligence. This dynamical systems analysis challenges the trait theory explanation by contradicting the very existence of a trait of *g*.

SUMMARY AND CONCLUSIONS

The trait theory perspective has proven extremely useful for exploring the psychometric structure of mental abilities and their educational, vocational, and health consequences. It has facilitated research showing that *g* is quite heritable, becoming more heritable with age (Richardson, 2013), that intelligence is correlated with health, lifespan (Gottfredson & Deary, 2004), and vocation (Gottfredson, 1986), and that intelligence is associated with specific genes (Wacker, Mueller, Hennig, & Stemmler, 2012; Zhu et al., 2014). Clearly, the trait theory perspective is central to gifted education, as demonstrated by the continued importance of intelligence in identification procedures (Mcclain & Pfeiffer, 2012). The usefulness of the trait theory perspective is in its provision of a term that captures general cognitive functioning, a framework for detecting and measuring this trait from diverse task performance (i.e., factor analysis), and its facilitation of research on the relationship between intelligence and its genetic and environmental antecedents, as well as its personal and societal consequences. From this perspective, it hardly matters whether intelligence as a trait really exists or if it is simply a label for the generalized efficiency of cognitive structures (i.e., executive function, working memory, and attention), for a large confederation of independent but cooperative subabilities, or a level of developed expertise in problem solving, completely mediated by the amount and character of deliberate practice.

From the perspective of trying to understand why people vary in their ability to reason, learn, and solve problems (i.e., their intelligence) the trait theory perspective becomes markedly less useful, even circular. Research reviewed in this chapter reveals some of the actions that gifted children do differently than their age peers that facilitate their precocious academic ability, illuminating the advanced metacognition that allows them to think strategically, to self-monitor, and to switch, modify, or abandon ineffective strategies, and to transfer learning across situations and domains. Clearly more work is needed in this area. An obvious question that results from this line of inquiry is whether gifted performance can be taught. In other words, if typical children could be taught to approach problem solving with the same strategic metaorientation, could their performance be improved?

We believe that all the perspectives considered in this review would agree that the ability of a person to successfully use metacognition while in the throes of nonautomatized, nonroutine problem solving depends on the capacity of the underlying cognitive architecture. When the low-level components of the task overwhelm the capacity of the cognitive system, there are simply no resources remaining to devote to high-level meta concerns. These are luxuries that simply cannot be afforded under such conditions.

Can gifted performance be taught? From the expertise development orientation, the answer to this question is a resounding yes. Intense, long term practice and training in a domain unlocks the cognitive superpowers—the dramatically increased chunking efficiency, the LT-WM, and the automatization of the routine aspects—that enable expert performance. With sufficient practice, the problem-solving effort requires fewer resources. In time, sufficient capacity has been restored to allow effort to be expended at the metastrategic level.

However, the expertise development facilitation of performance occurs only with extensive experience and practice. In a truly novel situation, these adaptations are simply unavailable. From a classical cognitive perspective, performance then is dictated by the capacity of the working memory system, the effectiveness of the executive function system, and the efficiency of attention. These can conspire to produce enough "slack" in the system to allow some attention to be devoted to the metalevel even while in the throes of executing the low-level operations of the task. From this point of view, gifted performance with respect to the novel is unteachable, because individuals with lower capacity cannot perform the actions that facilitate high performance without jeopardizing the execution of the basic operations themselves. In other words, attempting to improve the reading comprehension of a typical kindergartener by asking him or her to reflect on the plot is a fool's errand, as the child's resources are completely consumed by the effort of decoding the letters and words. Thinking about the plot would necessitate the child ceasing to decode the text.

We hope that future research in gifted studies will continue to illuminate the differences in function and capacity of fundamental cognitive machinery, as well as the specific learning and problem-solving behaviors that distinguish the highly intelligent from the average-ability learner. It is possible that such efforts will bear fruit in enhanced identification procedures and curricular interventions for advanced learners. They are, however, guaranteed to deepen our understanding of the internal structures and processes that create giftedness.

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