Talent Development in Achievement Domains: A Psychological Framework for Within and Cross-Domain Research

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Abstract

Achievement in different domains such as academics, music, or visual arts plays a central role in all modern societies. Different psychological models aim to describe and explain achievement and its development in different domains. However, there remains a need for a framework that guides empirical research within and across different domains. With the *talent development in achievement domains* (TAD) framework, we provide a general talent development framework applicable to a wide range of achievement domains. The overarching aim of this framework is to support empirical research by focusing on measureable psychological constructs and their meaning at different levels of talent development. Further, the TAD framework can be used for constructing domain-specific talent development models. With examples for the application of the TAD framework to the domains of mathematics, music, and visual arts, the review provided supports the suitability of the TAD framework for domain-specific model construction and indicates numerous research gaps and open questions that should be addressed in future research.

Keywords: talent development; achievement; giftedness; expertise; domain specificity; education

Talent Development in Achievement Domains: A Psychological Framework for Within and Cross-Domain Research

Achievement is defined both as the action of achieving something as well as the result accomplished through effort, skill, or courage in response to given conditions ("achievement," n.d., Oxford English Dictionary). Achievement in different domains such as academics, the arts, or sports plays a central role in all modern societies. For example, students' school achievement influences not only their current development but also exerts a life-long impact on variables related to socio-economic status (Slominski, Sameroff, Rosenblum, & Kasser, 2011) and health (Silles, 2009). From a societal perspective, professional sports like basketball or soccer have developed into multi-billion dollar markets; and professionals' achievements in science, technology, engineering, and mathematics drive the scientific and technological development of a country and contribute to its economic well-being and competitiveness (Halpern et al., 2007).

Given the central role of achievement in modern societies, several theoretical models from different scientific psychological strands like differential, educational, or industrial and organizational psychology; giftedness research; or research on expertise aim at explaining the development of achievement in general and of high achievement in particular (for overviews, see Hambrick, Macnamara, Campitelli, Ullén, & Mosing, 2016; Sternberg, 2004; Subotnik, Olszweski-Kubilius, & Worrell, 2019; for meta-analyses, see e.g., Hattie, 2009; Ng, Eby, Sorensen, & Feldman, 2005; Schneider & Preckel, 2017)[1]. People are not born as (high) achievers but eventually develop into such. From a psychological perspective, the development of achievement can be described as a process of talent development in which a person's potential for achievement develops into actual achievement. In this regard, some central research questions include the following. What constitutes potential for achievement? Can potential be measured and if yes, how? How does it develop into high achievement? Are there common principles of talent development across achievement domains like mathematics, music, or visual arts? How do developmental trajectories differ across domains? At what time points during the developmental process are particular interventions helpful or even necessary?

The current work aims to contribute to research related to these questions by suggesting a talent development framework that should be applicable to a wide range of achievement domains. This framework could act as a starting point for the development of domain-specific models, which, in turn, could be used for the description, explanation, prediction, and fostering of high achievement and its development in these domains. Such a framework would facilitate the synthesis of research findings from different domains and could identify generalizations across domains (e.g., general developmental processes) and specifications for particular domains (e.g., starting age or peaks of development). The framework could thus be extremely helpful for an integrative discussion of how to model talent development in different domains. Overall, such a framework could help to advance the field, which is in need of more systematic, sustainable programs of research, more coordination among researchers, and a stronger link between theory and practice (e.g., Dai, Swanson, & Cheng, 2011; Hambrick, Burgonye, & Oswald, 2019; Preckel & Krampen, 2016). The current work builds on existing formulations yet serves as a springboard for the development of a next generation framework for talent development. Accordingly, all ideas and conceptions presented here are open to discussion and further elaboration.

Fundamentals of the Talent Development in Achievement Domains (TAD) Framework

For the development of the framework, 12 researchers (i.e., the authors) from different fields of psychological research on talent development met for a two-day summit in Munich, Germany, to discuss talent development from multiple perspectives including music psychology, art psychology, educational psychology, differential psychology, giftedness research, research on expertise and instructional psychology. The goals for the summit included identifiying (a) requirements for a talent development framework, (b) common principles for talent development across achievement domains grounded in psychological science, (c) potential gaps in extant models, and also (d) coming up with research questions that had the potential to facilitate moving the field forward. These goals were pursued in full group discussions. Melding views into a collaborative effort meant engaging with intellectual and values-based disagreements, but eventually, the group reached consensus for a collaborative statement of needed work in the field. Subsequently, these ideas were further developed within a common writing project. Results are presented here.

First, we describe the requirements for the framework the group agreed upon. Second, as the framework builds on existing formulations—and especially on the megamodel by Subotnik, Olszewski-Kubilius, and Worrell (2011)—we summarize the model and its basic principles. Third, we outline the contributions of the TAD framework relative to the megamodel. Fourth, we describe the TAD framework in detail. Finally, to show the potential of the TAD framework for cross-domain applications, we demonstrate its application to different achievement domains like mathematics, music, and visual arts.

Requirements for the TAD Framework

Quality criteria for scientific theories include comprehensiveness, precision, testability, parsimony, empirical validity, and heuristic and applied value (Cramer, 2013). We do not claim to present a new theory of talent development, but we aim to offer a catalyst for the development of domain-specific talent development models. Therefore, these quality criteria guided the formulation of requirements for the framework. We elaborate on the requirements in the following paragraphs.

The framework *integrates different strands of psychological research.* An increasing number of recent papers on achievement and talent development integrate theoretical perspectives and empirical findings from different fields of psychology (e.g., Hambrick et al., 2016; Lubinski, 2016; Subotnik et al., 2011; Ullén, Hambrick, & Mosing, 2016). The TAD framework should mirror the comprehensiveness of these papers and integrate evidence for predictors of achievement and trajectories of talent development in different domains, based on research from different psychological fields including expertise, giftedness, or education and instruction (i.e., an evidence-based integrative approach).

The framework *reduces complexity and is in part testable.* The focus of the framework is on person-related psychological variables. We acknowledge the important role of environmental and genetic factors, as well as their complex interaction with each other and with person-related psychological variables, and we summarize main findings on the role of these factors in talent development in the section below entitled Environmental and Genetic Factors. However, these factors are not emphasized in the framework itself because they would make it too complex to be ~~falsifiable~~empirically testable. Rather, we investigate these factors on talent development as they reflect on person-related psychological variables (e.g., reception of opportunities offered by the environment). The focus on person-related psychological variables facilitates assessment and the formulation of testable hypotheses deduced from the framework.

The framework *uses clear and consistent construct definitions.* To avoid using different terms for the same constructs or the other way round and to allow for the integration of research findings from different domains and research strands, it is of utmost importance to have common definitions of central terms. We therefore offer our definitions of central terms when presenting the TAD framework (see below).

The framework *offers a ranking of predictors according to their importance at different developmental levels to predict talent development.* The focus of the framework is on person-related psychological variables, which comprise a wide variety of cognitive, non-cognitive, and psychosocial constructs. These constructs differ in stability and have their own developmental trajectories. Further, what constitutes achievement and what is required for it varies over time and developmental level (e.g., demands vary for beginners or advanced learners in a domain). The framework considers this concern and formulates hypotheses for the relative importance of different cognitive, non-cognitive, and psychosocial constructs in the process of talent development.

The framework *integrates psychological processes and their specificity for the development of high achievement.* The framework outlines general principles and processes of talent development (e.g., learning) as well as aspects that are more specific for the development of high achievement (e.g., profile formation and specialization) within specific domains or for specific groups. It further integrates these processes into the overall talent development process to allow the formulation of hypotheses (e.g., regarding temporal order).

The framework *defines potential outcomes within the process of talent development.* Talent development is understood as a cumulative process in which earlier outcomes (achievements) influence later outcomes (achievements). The framework defines potential outcomes at various levels of talent development that, in turn, influence achievement development in the future. However, the framework does not define any normative results or ceiling for talent development.

The framework *informs identification, fostering, and counselling.* The general framework, as well as the domain-specific models, should provide information about indicators for early/middle/late outcomes of talent development. These should be specific enough to be used for the identification of achievement potential and for tracking progress in a talent domain. The framework further informs interventions suitable for supporting specific changes and progress in the talent development process.

Point of Origin: The Megamodel of Talent Development

The megamodel (Subotnik et al., 2011) provides a synthesis of the psychological science behind talent, giftedness, and expertise (see Figure 1 with notation below). Therefore, it was used as the springboard for the TAD framework. Similar syntheses are also provided by other authors (e.g., in the multifactorial gene–environment interaction model by Ullén et al., 2016). However, the megamodel includes a developmental (long-term) perspective that is needed to describe talent development in different achievement domains.

Figure 1 about here

The megamodel describes the talent development process from potential to eminence[2] by four successive levels: ability, competence, expertise, and eminence (Jarvin & Subotnik, 2010). Transition between those levels is distinguished by creativity as a source of identification (person), a creative use of knowledge (process) toward competence and expertise, and in the later stages of talent development trajectories, the creation of new ideas and domain contributions (product). The basic principles behind the megamodel are as follows.

1. *Abilities are important for high achievement, both general abilities and domain-specific abilities*. Individual differences exist in both sets of abilities, yet they remain malleable and need to be developed to achieve individual goals. The predictive validity of general and

domain-specific abilities is well established in academic domains with domain-specific abilities having a strong and consistent positive effect on creative productivity (e.g., Lubinski, 2016) or in the work place for the prediction of job performance and training success (Bertua, Anderson, & Salgado, 2005). However, many domains remain unexplored with regard to identifying which constellation of general and domain-specific skills are necessary, even if not sufficient, to allow for successful continuation in a field or domain.

2. *Each domain of ability has different beginning, peak, and end points. As a consequence of these varying trajectories, abilities in some domains are not evident until later in a school career, whereas others are recognizable early* (see Figure 2). The existence of varied trajectories (Simonton, 1997, 2001) has implications for serving talented youth. For example, some (although not all) children with potential for deep involvement in mathematics can be engaged early in the school years with creative and advanced work, and many careers in mathematics begin earlier than in other domains. Differences in trajectories can be seen most explicitly in performers where physiological differences impede or enhance functioning, such as lung power in wind instrument players and flexibility in female gymnasts. A violinist entering a music conservatory at age 18 tends to be far more experienced in the music world than a clarinetist, having started her trajectory at age 4 or 5 rather than age 12 (Subotnik, 2004). Finally, some important achievement domains require human experience and understanding of human behavior, such as diplomacy or health care, and thus are introduced in early adulthood.

3. *Abilities that are not deployed do not develop, and appropriate opportunities must be offered at appropriate times.* Some of the most seminal work on the role of instruction for talent development was derived from the work of Bloom and his colleagues (Bloom, 1985). Early

teachers and families provided occasions for playful engagement with a domain, leading to falling in love with or developing a passion for the domain, whereas later teachers focused on developing skills and expertise, ultimately helping the student or tutee develop a unique niche or voice. The most important outcome of these explorations into elite athletes, artists, and scholars was to show that what they needed in terms of opportunities and instructors or coaches changes over time (for reviews on the role of instruction for academic achievement, see, Hattie, 2009; Schneider & Preckel, 2017).

4. *Mental and social skills transform abilities into competencies, expertise, and creative productivity.* They play a major role in individuals' receptiveness to opportunities. The development of one's own abilities requires that a person has the confidence or motivation to take advantage of opportunities or the autonomy to seek them out (e.g., Noble, Subotnik, & Arnold, 1996). Mental and social skills are important for dealing with obstacles to progress and pushback against creative ideas, for investing abilities, or long-term commitment (for an overview on the role of psychosocial skills in K-12 education, see, Lipnevich, Preckel, & Roberts, 2016).
5. *Finally, talent development is not limited to the school year and curriculum.* Rather, talent development incorporates extra and co-curricular activities, and involves a long-term view of advising talented children and youth on activities and educational institutions that will best serve them in meeting their individual goals.

Figure 2 about here

The TAD Framework Relative to the Megamodel

The TAD framework (see Figure 3) draws heavily on the megamodel. It adopted the basic principles of the megamodel described in the preceeding section. It describes the talent development process by four successive levels (Column 1 of Figure 3: "Developmental Levels") and it follows the notion of a trajectory in talent development moving from general abilities to specific skills and competencies (Column 2: "Increasing Specialization"). It conceptualizes talent development as dependent on a multiplicity of factors whose relative importance can vary with level of talent development (Columns 3 & 4: "Level-dependent predictors and indicators").

Figure 3 about here

However, the TAD framework provides some departures. Whereas the megamodel emerged from a descriptive synthesis of the literature, the TAD framework goes a step further by making talent development more suitable for empirical investigations and more usable for cross-domain applications. Some specific characteristics of the TAD framework, which follow from this elaboration, include the following:

- A primary psychological focus on measureable, person-related variables to reduce complexity and to promote testability.
- A stronger focus on internal processes that lead to interest and success in a domain (e.g., ability differentiation, profile formation, identity formation). Particular attention is drawn to the formation and specific role of ipsative ability-personality profiles because previous research has shown that these profiles are highly predictive of individuals' achievements and domain choices (e.g., Lubinski, 2016; Wang, Eccles, & Kenny, 2013; Wang, Ye, & Degol, 2017).
- A suggestion of important predictors and indicators of talent development at different levels of the talent development process. These predictors and indicators can be assessed empirically and can therefore be used to identify achievement potential at various levels and to track progress in the talent domain. Further, and in accordance with the megamodel, TAD

acknowledges that within the process of talent development the relative importance of predictors can vary. For example, the validity of agreeableness for explaining academic performance seems to decrease with educational level (Poropat, 2009). The TAD framework therefore suggests prioritizing the investigation of predictive contributions to the next sequential level of talent development, rather than long-term contributions toward transformational achievement.

- Like the megamodel, the TAD framework should be transferable to different domains in which the framework guides model development. The TAD framework offers some guidelines and examples for this endeavor. For example, the framework scaffolds model development by differentiating levels with their respective predictors and indicators of talent development. The creation of a domain specific talent development model requires outlining evidence for each part of the framework related to the respective domain, deducing evidence-based applications (assessment, intervention), pointing out gaps in the literature and suggesting a research agenda for specific domains. In the section, “Application of the TAD Framework to Different Achievement Domains” (see below), we present examples for uses of the TAD framework for model development in music, mathematics, and the visual arts.

TAD Framework Description

Developmental Levels

As depicted in Figure 3, the first column of the TAD framework provides a basic orientation to lifespan development, closely paralleling aspects of the megamodel (Subotnik et al., 2011). With increasing levels of talent development, the number of persons decreases (Simonton, 1999), as suggested by the triangle in that column. In the following, we give definitions for the levels and describe what they entail.

Aptitude refers to variations in individuals' constellations of psychological factors that are predictive of a positive development of achievement or future performance. It reflects individual differences in psychological variables (e.g., musicality, mathematical cast of mind, spatial ability) that would predispose a person to becoming interested in or engaging in activities relevant to a particular kind of achievement domain[3]. In some domains, these may manifest themselves very early, in others, later. However, they tend to have a quality of a *natural* fit between the person and the content or challenges of that activity. In the megamodel, the term "ability" is used for this level. However, we understand that ability refers to variations in an individual's capacity for *present* performance on a defined class of tasks (Carroll, 1993, p.16). To stress the meaning for the *development* of achievement or *future* performance, the term "aptitude" is used in the TAD framework.

Competence refers to a cluster of related and systemically developed abilities, knowledge, and skills that enable a person to act effectively in a situation and that result from systematic learning (Gagné & McPherson, 2016). Once individuals who have demonstrated some aptitude for an activity have engaged in it for a while, their performance typically improves, setting them apart from their peers. Often, this growth is accomplished under formal tutelage. Individuals acquire a variety of increasingly domain-specific skills giving them multiple options to act efficiently, and may see themselves headed toward a career in that domain.

Expertise refers to a high level of consistently superior achievement; an expert has a strong grasp of the field or domain such that he or she is capable of generating good solutions to important domain problems (Subotnik et al., 2019). This step typically involves overt commitment to a domain, with a concomitant increase in knowledge base and yet more domain-specific skills, often acquired through lots of particularized education. Even with the acquisition of considerable expertise, depending on the domain, transitioning to full-time professional status can be difficult. Although reputation does not ensure a high level of expertise (Ericsson, 2006), the acquisition of a full-time professional status usually requires the recognition as an expert by others similarly engaged in the domain. Relatedly, the provision of insider knowledge is frequently helpful, as are well-developed psychosocial skills.

Transformational achievement refers to levels of achievement that go beyond expertise by generating creative responses that require breaking domain boundaries or setting new questions. This outcome can comprise a single significant contribution or sustained contributions that have had or will have a lasting and memorable impact on how work in the field is conducted (Jarvin & Subotnik, 2010; Subotnik, Olszewski-Kubilius, & Worrell, 2018). For those lucky or skilled enough to successfully navigate the socio-cultural and chance factors that can quash hopes for a professional career in one's chosen achievement domain, one still faces the challenge of taking experience and expertise and translating it into some kind of tangible achievement, often of a strongly creative variety, and of sustaining that mode into later life. Our understanding of transformational achievement resembles the description of eminence in the megamodel. However, the term, eminence, can easily be misunderstood (for a discussion, see, Worrell, Subotnik, & Olszewski-Kubilius, 2018). Therefore, we use the more descriptive term, transformational achievement, within the TAD framework.

Increasing Specialization

Column 2 of Figure 3 focuses on the increasing specialization of talent across achievement levels. People usually do not achieve at the same level in different domains. That is, high achievement is most often domain specific because it results from intensive investment and engagement that draws off time for investment and engagement in other activities. This focus indicates a process of increasing specialization within talent development. Within the TAD framework, we assume the following five principles and processes behind this specialization process.

First, general and specific cognitive abilities are important during the whole process of talent development. There is overwhelming evidence for interindividual differences in psychological variables related to achievement in general (e.g., intelligence or conscientiousness; Ng et al., 2005; Nisbett et al., 2012; Richardson, Abraham, & Bond, 2012; Schneider & Preckel, 2017; Strenze, 2007) as well as for high levels of achievement (Hambrick et al., 2016; Lubinski, 2016). The predictive validity of general and specific cognitive abilities is well established. In their review of the literature on changes in the validity coefficients associated with general cognitive ability tests due to the passage of time, Reeve and Bonaccio (2011) concluded that "scores based on measures of *g* can predict outcomes over long periods, with only minimal (if any) degradation in the magnitude of the criterion-related validity coefficient over time" (p. 264). General cognitive ability remains a significant predictor of job performance even after extensive job experience (for an overview, see Hambrick et al., 2019). In their meta-analyses, Zaboski, Kranzler, and Gage (2018) found positive relations of general and more specific cognitive abilities with academic achievement, with general cognitive abilities having the largest effect across all achievement domains and ages (mean effect size of $r^2 = 0.54$). Moreover, earlier domain-specific abilities have a strong and consistent positive effect on later creative productivity, job performance, or training success (Bertua et al., 2005; Lubinski, 2016).

Second, general and specific cognitive abilities are malleable. Even general cognitive ability that, in relative terms, is a rather stable characteristic of people shows some variation across the life span: Around half of the individual differences in general cognitive ability are stable across most of the human life course, but the other half are not (Deary, 2014). Lyons et al. (2009) found that over a time span of 35 years (between age 20 and age 55), 44.6% of the individuals had score changes of half of a standard deviation or more in a measure of general cognitive ability. Environmental factors contribute to a comparable amount as genetic factors to individual differences in measures of cognitive ability (Knopik, Neiderhiser, DeFries, & Plomin, 2016). A case in point is education. A recent meta-analysis by Ritchie and Tucker-Drob (2018) revealed a significant impact of education on the development of cognitive abilities. The authors reported beneficial effects of education on cognitive abilities of approximately 1 to 5 IQ points for an additional year of education which persisted across the life span and were present on all broad categories of cognitive ability studied. In addition, findings from longitudinal studies with students in the German, three-track, secondary school-system indicate that the development of students' general cognitive ability partly depends on the school track that the students attended (Becker, Trautwein, Lüdtke, Köller, & Baumert, 2012; Guill, Lüdtke, & Köller, 2017).

Third, abilities differentiate and become more specific over time. Achievement in most domains relies on the ability to learn, to understand new content, and to solve problems. This general ability can be described as intelligence, conceptually defined as "a very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience" (Gottfredson, 1997, p. 13). Different theoretical accounts assume that general ability is foundational for the development of more specific abilities. In his theory of intelligence development, Garret (1946) introduced the concept of ability differentiation with increasing age and ability, assuming a structural change of intelligence from a single factor *g* (i.e., general intelligence) to various specific factors.

Cattell's (1987) investment theory postulates that rather general, fluid abilities are invested into the acquisition of crystallized abilities (e.g., specific knowledge or skills) by taking advantage of learning opportunities. When the environment becomes more heterogeneous as life unfolds, crystalized abilities, which are more strongly impacted by the environment, do so as well; however, fluid abilities do not. This contrast, in turn, leads to a differentiation of abilities and to the development of more specific abilities or specialized knowledge structures. Similar ideas are expressed in Ackerman's (1996) intelligence-as-process, personality, interests, and intelligence-as-knowledge (PPIK) theory. Empirical evidence does not support a general shift in intelligence structure, but it supports the assumption of a differentiation of factors that refer to more specific acquired contents and skills (*crystallized intelligence* or *intelligence-as-knowledge*; Carroll, 1993; Schalke et al., 2013).

Fourth, ability development is intertwined with personality development. Theories of intellectual development (e.g., Ackerman, 1996; Ziegler, Danay, Heene, Asendorpf, & Bühner, 2012) and theories that include the development of achievement (e.g., Marsh & Martin, 2011) intertwine ability development with personality development. For example, in Ackerman's (1996) PPIK theory, the transition from more innate perceptual and information-processing components of intelligence (e.g., speed, reasoning, working-memory) to acquired knowledge and skills is assumed to be influenced by personality traits and interests. A case in point are so-called intellectual investment traits (e.g., need for cognition) that determine when, where, and how people invest their time and effort in the development of their abilities and intellect (von Stumm & Ackerman, 2013). Further, the development of abilities and interests is assumed to proceed along mutually causal lines such that ability levels determine the probability of success in a particular task domain, which in turn increases interest in this task, and personality and interests determine the motivation for attempting the task.

The openness-fluid-crystallized-intelligence (OFCI) model (Ziegler et al., 2012) further assumes positive reciprocal relations between the personality factor openness and fluid intelligence (“intelligence-as-process” in PPIK). On the one hand, being open brings about more learning opportunities, which positively affects the development of fluid intelligence (“environmental enrichment” process); on the other hand, fluid intelligence, partly mediated by its investment into building up knowledge and skills, positively affects openness because it increases the likelihood of successfully managing tasks (“environmental success” process). Similar positive reciprocal effects have been theoretically assumed and empirically supported for the relation between academic achievement and academic self-concept (reciprocal-effects-model REM; Marsh & Martin, 2011). That is, the development of ability factors and in particular of more specific abilities or specialized knowledge and the development of nonability factors (e.g., self-concept, interests, investment traits) are related to each other within the process of talent development that results in the development of specific ability-personality profiles (e.g., being a “math person” with high abilities, investment, interest, and academic self-perceptions related to math).

Fifth, ability-personality profiles inform talent development. A process of ability differentiation that is intertwined with the development of non-ability factors (see above) leads to the formation of ability-personality profiles that differ among persons (e.g., Ackerman, 1996). These profiles comprise individual constellations of abilities, interests and values, motivational variables, or self-concepts that inform further talent development over a wide range of achievement levels including exceptional achievement (Ackerman & Heggestad, 1997; Snow, 1991). Although mean levels of achievement-related factors are useful for predicting the achievement level of an individual, an individual's ability-personality profile is useful for predicting domain selection and the domain in which the person achieves best (Coyle, Purcell, Snyder, & Richmond, 2014; Coyle, Snyder, & Richmond, 2015; Dekhtyar, Weber, Helgertz, & Herlitz, 2018; Lubinski, Webb, Morelock, & Benbow, 2001; Makel, Kell, Lubinski, Putallaz, & Benbow, 2016; Park, Lubinski, & Benbow, 2007, 2008; Wang et al., 2013, 2017).

Of note, ability-related profiles seem to be more scattered in high-ability individuals (Lohman, Gambrell, & Lakin, 2008). Spearman's (1927) law of diminishing returns (SLODR) describes this phenomenon as a special case of ability differentiation: With increasing ability level, correlations among different ability factors decrease. Stated differently, SLODR refers to ability-dependent differences in loadings of the general intelligence factor *g* on more specific ability factors (i.e., smaller *g*-loadings with increasing general ability level). A review (Hartmann & Nyborg, 2004) as well as a recent meta-analysis (Blum & Holling, 2017) both found significant support for the SLODR-hypothesis. Studies further indicate SLODR effects not only in older but also in younger age groups (e.g., kindergarteners: Tucker-Drob, 2009; 6-18 year olds: Reynolds & Keith, 2007).

In sum, ability-personality profiles are important to understand domain choices or, more generally, the process of specialization within talent development. Investment and success in a domain reinforce identification with the domain (e.g., by self-concept formation) which, in turn, enhances investment and success (Marsh & Martin, 2011). The formation of an identity as an expert in a respective domain (e.g., being able to say "I am a psychologist" instead of "I study psychology") supports self-efficacy which is needed for further investment, self-regulation within the investment process, and creative productivity (Bledow, Rosing, & Frese, 2013). Thus, there are positive reciprocal effects between ability-personality profiles and achievement. As empirical evidence points to more differentiated ability profiles among high-ability individuals, these profiles might be especially important for understanding talent development in these same groups. In high-ability groups, an individual's ability-personality profile seems not only to be predictive for the chosen domain but also for creative productivity within that domain (Lubinski, 2016). Further, ability-personality profiles might also predict the likelihood of being able to move to a higher level of achievement. Usually, only current levels of achievement are used to make this prediction, but future achievement is dependent on a host of other factors that reveals little about the readiness of the individual for what is required at the next stage of talent development. Research on ability-personality profiles in this context seems to be a promising direction for understanding and supporting talent development.

There are several open questions regarding specialization. If talent development follows a trajectory of increasing specialization as assumed in the TAD framework, then several important questions arise. Is there an optimal point in time for focusing on one domain or activity within that domain (e.g., is earlier specialization better than later specialization)? Should a person choose a main activity and drop others to invest in that activity (a priori specialization) or should a person choose one main activity from multiple activities the person has invested in (a posteriori specialization)? Do answers to these questions vary for different activities within a domain and among domains? Although the concept of deliberate practice suggests that early specialization is beneficial for talent development (Ericsson, 2006; Ericsson, Krampe, & Tesch-Roemer, 1993), research from the domain of sports suggests that in senior elite sports, highly successful athletes were characterized by later specialization and greater amounts of organized involvement in other sports than less successful athletes, although both groups did not differ on the amount of sport-specific deliberate practice (Güllich, 2014, 2017, 2018).

Güllich (2018) used the *multiple sampling and functional matching hypotheses* to explain ~~the~~ these findings: Rather than "putting all eggs in one basket" from the outset, more successful athletes' participation patterns implied that they opened various career options, furthered them simultaneously over multiple years, and kept them open for a relatively long time. The election of the main sport emerged from athletes' own experiences of various sports and thereby multiplied the probability of electing the sport of individual "best fit" (Güllich, 2018, p. 2262). Moreover, experiences with other sports might have led to diversified learning experiences that increased different skills and the process of motor learning in itself (*learning transfer as preparation for future learning hypotheses*; Güllich, 2018). To conclude, for the domain of sports and independent of the general amount of deliberate practice, later specialization seems to be associated with higher adult performance compared to early specialization; comparable research for other achievement domains is missing.

Level-Dependent Predictors and Indicators

The final two columns of Figure 3 address level-dependent predictors and indicators. Like the megamodel, TAD understands talent development as a cumulative process in which the relative importance of predictors varies over time or level of talent development (i.e., aptitude, competence, expertise, transformational achievement). That is, some variables like general cognitive ability or motivation can be important from early on and remain important throughout the person's development. Others, like social skills can gain in importance as the individual transitions from being a novice student to become an advanced student or professional. Beyond that, the TAD framework aims to describe which predictors and indicators should be assessed empirically at various levels. These serve to identify *potential as an individual's constellation of psychological factors that indicate the likelihood of a positive development of achievement to the next level*. Accordingly, what defines potential can change with level, allowing for tracking progress in the talent domain.

The choice of appropriate psychological features to serve as predictors and indicators of talent development depends on the specific domain and developmental level (see section, "Application of the TAD Framework to Different Achievement Domains"). Psychological variables with predictive power for describing talent development at different levels include cognitive variables (e.g., intelligence, working memory, perceptual abilities, creativity), personality variables (e.g., openness and further investment traits, conscientiousness, emotional stability), motivational variables (e.g., achievement motivation, interests, values, self-concept), and psychosocial skills (e.g., resilience, empathy, receptiveness to feedback, a growth mindset) including self-regulatory skills (e.g., coping, goal setting, self-regulated learning; for overviews see Jarvin & Subotnik, 2010; Lipnevich et al., 2016; Ng et al., 2005; Schneider, 2000; Schneider & Preckel, 2017; Strenze, 2007).

Within the TAD framework, it is assumed that at the *aptitude* level, factors like general cognitive ability, openness, and achievement motivation are highly relevant for talent development indicated by ease and speed of learning and responsiveness to learning new content and skills. For acquiring *competence* in a given domain, more specific abilities related to that domain and its choice as well as successful learning become highly relevant; these include associated personality factors (e.g., investment traits, conscientiousness, or self-concepts) as well as interests and values (Ackerman, 1996; Holland, 1997). At the *expertise* level, learning abilities are no longer sufficient and need to be complemented by the intelligent application of gained knowledge and skills, which requires more developed and advanced meta-cognitive skills. In most domains, persuasive strategies to sell one's expertise necessitate social competencies and a sensibility for opportunities (Sternberg & Lubart, 1991, 1992).

Finally, making a *transformational achievement* that moves a domain's boundaries entails keeping up investments at a high level, which requires persistent motivation and psychological strength, like the ability to cope with rejections and failures and the keep up faith in oneself (Jarvin & Subotnik, 2010). Moreover, it can become important to make one's work visible and to convince others, enhanced by a set of characteristics sometimes termed as "charisma." The concept of charisma is mainly discussed within theories of leadership (Dinh et al., 2014) and is associated with a transformational leadership style (Bass, 1990). The two sub-dimensions of transformational leadership, "idealized influence" and "inspirational motivation," can be combined under the designation of charisma (Phaneuf, Boudrias, Rousseau, & Brunelle, 2016).

The generic structure and specification of TAD as an empirical prediction model is very straightforward. For empirical investigations, one could use linear regression models or other predictive statistical models that accommodate non-linear relations, variance in change rates, multi-level structures, interactions, or moderators and mediators. The accuracy of an empirical TAD model can be expressed in terms of *R*-squared or some other measure of model fit. The more a set of predictors explains in the variance of an outcome measure, the better the prediction of a TAD model. Model predictions are likely to be more accurate for shorter time intervals and more fine-grained increases in achievement (represented by the breath of the arrows in Figure 3). Hence, choosing shorter time intervals can be beneficial for model construction and will require fewer changes to the assessment of psychological features and achievements in a given domain.

TAD suggests investigating predictors' validity within one level and between adjacent levels rather than focus on long-term predictive validity. Models from the TAD framework therefore do not rely on the assumption that individual psychological variables need to have strong predictive power across long-term developmental spans (i.e., not relying on the assumptions that a test taken at age 5 can predict high achievements at age 20 with sufficient accuracy). Instead, achievement outcomes of a given developmental level, that is, indicators of talent development within this level, are predicted primarily by psychological variables assessed at the beginning of the same level. However, for successive levels, we assume a considerable overlap in appropriate predictors and indicators. In addition, the relative importance of predictors over time might differ. It is also important to note that within TAD the levels of talent development are not defined in terms of chronological age, but in terms of positions on the developmental trajectory (see also, Jarvin & Subotnik, 2010). Whether and how these levels might be linked to critical time windows measured with respect to chronological age needs to be determined in future research on domain-specific talent development.

To conclude this section, the TAD framework allows for a systematic comparison of domains regarding psychological predictor variables. Some psychological variables will be domain-specific but others can be powerful predictors that are common to more than one domain. It is then an empirical question to identify significant predictors shared across domains. The assessment of achievements, however, will be entirely dependent on the domain (e.g., mathematics, music, visual arts; see section "Application of the TAD Framework to Different Achievement Domains") and needs to consider the developmental level. Table 1 offers a summary of the main ideas of the TAD framework.

Table 1 about here

Environmental and Genetic Factors

In order to reduce complexity and facilitate the formulation of testable hypotheses deduced from the framework, TAD's primary focus is on person-related psychological variables. Nevertheless, talent development clearly hinges on multiple environmental and genetic factors.

Environmental Factors: The Role of Learning Opportunities and Instruction

Successful talent development at the aptitude level requires that a child has many opportunities for learning, trying out new things, and coming into engaging contact with different domains; also important are exercising the beginnings of deliberate practice and competent teachers (Jarvin & Subotnik, 2010; Subotnik et al., 2011). Further, students should have access to advanced content that typically becomes interesting at an older age. At the competence level, regular intense learning experiences within the child's zone of proximal development in a domain (Ericsson et al., 1993; Vygotsky, 1978) are essential. Learning conditions and settings are needed that allow meaningful learning (e.g., scaffolding, acceleration, enrichment, special schools or programs), acquiring strategies for independent learning, maintaining high levels of motivation, and finding a place within the learning setting where personal needs are fulfilled (e.g., finding friends, being accepted by teachers and classmates) (Hattie, 2009; Ryan & Deci, 2017).

In addition, many learners need support in overcoming certain social and societal hurdles and limitations (e.g., gender role stereotypes, social class) and in coping with possible experiences of feeling different (derived, for example, by separation from origin, family, ethnic group) experienced through educational and social advancement. Here, personal mentors in the broadest sense can take on a very important role (Subotnik & Jarvin, 2005). At higher levels of talent development, important environmental factors include the time and place for an intensive study of the domain (Lee, 2016). These factors are related to the possibility of financial support or to the compatibility of work and family life. Additional factors include exchange and collaboration with a community of colleagues in the field (Subotnik & Jarvin, 2005).

Genetic Factors: The Role of Gene-Environment Interplay

As outlined in the preceding section, talent development is impacted by the environment and the experiential effects related to it (e.g., opportunities, practice, instruction). These experiential effects, in turn, dynamically interact with genetic factors and influence individual (talent) development. Within this so-called gene-environment interplay, genetic effects moderate experiential effects and the other way round which, over time, can lead to correlations between specific genetic and experiential effects (Tucker-Drob, 2018). For instance, Mosing, Madison, Pedersen, Kuja-Halkola, and Ullén (2014) investigated a large sample of Swedish twins and found that, for the domain of music, the inclination to practice itself was substantially heritable (40%–70%).

The dynamic processes related to this complex interplay can be illustrated with the *Matthew effect* whereby initial differences magnify over time (e.g., "the bright get brighter"). For example, children with higher fluid intelligence that is partly based on genetic factors (e.g., Knopik et al., 2007) are able to learn more successfully than less intelligent children, as higher fluid intelligence predicts higher learning gains (e.g., Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009; Wang, Ren, & Schweizer, 2017). This experience and the feedback related to it can motivate more intelligent children to rely more on their cognitive abilities, to invest in their learning, and to actively seek out or evoke situations in which their cognitive abilities are stimulated. That is, interindividual differences of a genetically influenced trait[4] can lead to differences in learning gains and in the selection and evocation of environmental experiences (i.e., experience-producing drives; Bouchard, 1997). Absolute pitch (Ruthsatz, 2014) or figure drawing (Arden, Trzaskowski, Garfield, & Plomin, 2014) are further examples for traits with a genetic underpinning that predict talent development in music and visual arts, respectively. Thus, one's genetic makeup influences the experiences and activities that one seeks out, leading to differential profiles of talent development by genotype (Tucker-Drob, 2018).

Preconditions for the selection and evocation of "fitting" environments are the availability of and access to different options as well as resources to help shape environments. With increasing age and knowledge, a person's autonomy and resources usually increase to select and evoke fitting environments (Scarr & McCartney, 1983), and, in better fitting environments, genetic effects on talent development might even increase (Briley & Tucker-Drob, 2014). Stated differently, with increasing specialization or expertise, one might assume stronger genetic effects for talent development. For example, in the domain of music, Hambrick and Tucker-Drob (2015) found that genetic effects on music accomplishment were stronger among adolescents who engaged in music practice as compared to adolescents who reported not practicing; this finding suggests that genetic effects for skilled performance increased with practice. Moreover, Vinkhuyzen, van der Sluis, Posthuma, and Boomsma (2009) analyzed data from multiple achievement domains and found stronger genetic evidence for exceptional achievement in a specific domain as compared to average achievement.

To conclude, genetic and environmental factors are of utmost importance for talent development in different achievement domains. Their significance is recognized within the TAD framework. However, to make the framework more parsimonious and open to empirical investigation, genetic and environmental factors are not specified within the TAD framework depiction (see Figure 3). Rather, their impact is assessed through the psychological lens of the person (e.g., by individuals' report of their experience-producing drives or the opportunities realized by the person). For models including environmental and genetic factors, see Gagné and McPherson (2016) and Ullén et al. (2016).

Application of the TAD Framework to Different Achievement Domains

Here we present examples for uses of the TAD framework for model development in three domains (i.e., mathematics, music, visual arts). Each example is structured in the same way. First, the current state of talent development research in a domain is provided. Second, in line with the TAD framework, the development of aptitude to transformational achievement is described as a sequence, and empirical evidence is summarized that represents increasing specialization and links level dependent predictors and indicators to the talent development in that domain. Of note, TAD is a psychological framework aiming to allow predictions based on the measurement of constructs. Therefore, the focus is on psychological predictors and indicators for which rigorous measurement approaches are available. Third, literature gaps and an outlook for future research are discussed.

Mathematics

Mathematics differs from most other achievement domains in that it is a core subject in school and everyone is expected to attain a level of mathematical competence that enables them to deal with typical demands and situations in adult life. This competence level, which is also called numeracy or mathematical literacy, however, is not attained by a surprisingly large proportion of the population. Approximately 5–7% of individuals suffer from a mathematical learning disorder (dyscalculia; Butterworth, Varma, & Laurillard, 2011), and around 20% of adults show mathematical difficulties imposing practical and occupational restrictions (Litster, 2013; Organisation for Economic Cooperation and Development, 2013). Against this background, most psychological research has focused on atypical and typical mathematical development covering the range from poor to average achievement. Within this area of research, particular emphasis has been put on basic numerical abilities (e.g., understanding cardinality), which are assumed to represent the cognitive foundation for acquiring higher-order mathematical competencies.

Accordingly, most psychological models in this domain are restricted to the development of these basic numerical abilities in preschool and their importance for the acquisition of arithmetic skills in school (e.g., LeFevre et al., 2010; Siegler & Braithwaite, 2016). There are few psychological models on mathematical talent development that go beyond mathematical competencies taught in school or that specifically address high levels of achievement (e.g., expertise; but see Krutetskii, Teller, Kilpatrick, & Wirszup, 1976). Notably, only in mathematics education, there are some frameworks describing different types of mathematical thinking (from conceptual-embodied to axiomatic-formal; Tall, 2008) or levels of talent (e.g., Usiskin, 2000), but they do not include specific assumptions on the psychological underpinnings and predictors for different developmental levels. Therefore, the TAD framework has great potential to provide an elaborate theoretical foundation for a comprehensive model of mathematical talent development.

Aptitude. Valuable insights into the aptitude level of the TAD framework come from research on basic numerical abilities and functions in atypically and typically developing preschool children. This research has identified a set of early domain-specific abilities that are associated with (in some cases predictive of) mathematical competencies acquired in school. For instance, longitudinal research starting with kindergarten children and following them up until the end of elementary school has demonstrated the importance of early awareness of numerical quantities and their relationship for subsequent development of mathematical competencies (e.g., Krajewski & Schneider, 2009).

Research focusing on young school children has revealed that an adequate understanding of the properties of numerical information is a critical prerequisite in mathematical development. This comprises *cardinality* (i.e., numerical quantity) as well as *ordinality* (i.e., numerical sequence) information. Cardinality processing is typically assessed by means of number comparison tasks, in which children have to choose the larger of two numbers (presented either as Arabic digits or dot patterns). Better performance on this task has been found to be associated with higher mathematical competencies (Elliott, Feigenson, Halberda, & Libertus, 2019; Hawes, Nosworthy, Archibald, & Ansari, 2019; Schneider et al., 2017), even in older populations with higher achievement (Wang, Halberda, & Feigenson, 2017). The processing of ordinality information has been tested frequently by asking participants whether number triplets are in order (ascending or descending) or not. Likewise, the performance on this task has turned out to be associated with school-taught mathematical competencies (Lyons, Vogel, & Ansari, 2016). Recent research suggests that the importance of individual differences in both abilities changes over development, with cardinality being more relevant at the beginning of primary school and ordinality increasing its association with arithmetic skills later on (Lyons, Price, Vaessen, Blomert, & Ansari, 2014; Vogel et al., 2017). Both cardinality and ordinality understanding have been found to be impaired in children with dyscalculia (Butterworth et al., 2011; Morsanyi, van Bers, O'Connor, & McCormack, 2018).

Second, considerable individual differences in domain-specific attentional processes, which are also correlated with later mathematical competencies, have been observed. The most prominent concept is *spontaneous focusing on numerosity* (SFON), which refers to the individual tendency to spontaneously (i.e., in a self-initiated way) focus attention on numerical information in the surroundings (Hannula & Lehtinen, 2005). Individual differences in this tendency were originally assessed by a task in which children imitated actions of the experimenter that involved quantity information (e.g., feeding a stuffed bird with a certain number of berries); however, there is a wide range of different SFON measures. Cross-sectional as well as longitudinal studies have revealed that the individual SFON tendency is related to later mathematical (in particular arithmetic) competencies, over and above other basic numerical and domain-general abilities (Rathé, Torbeyns, Hannula-Sormunen, De Smedt, & Verschaffel, 2016). In the past few years, further spontaneous attentional tendencies have been proposed. School children's spontaneous focusing on quantitative relations (SFOR) is related to later conceptual knowledge of fractions and algebra (McMullen, Hannula-Sormunen, & Lehtinen, 2014). Kindergarteners' spontaneous focusing on Arabic number symbols is associated with their numerical abilities (SFONS; Rathé, Torbeyns, De Smedt, & Verschaffel, 2019).

Finally, there are two types of basic numerical tasks that are also associated with mathematical competencies but which may not be purely domain-specific. The number line estimation task requires children to locate a given number on an empty number line, thus also requiring the processing of cardinality information (Siegler, 2016). Interestingly, the performance on this task has been found to be more strongly related to different measures of mathematical competencies than that in the number comparison task (Schneider et al., 2018). However, it is an unresolved issue whether and to what extent this task draws on non-numerical functions (e.g., spatial abilities, proportional reasoning) besides cardinality processing. A similar limitation holds true for patterning tasks. Since patterns are considered central to mathematics learning, tasks were developed to assess children's early patterning abilities (Wijns, Torbeyns, De Smedt, & Verschaffel, 2019). In many of these, figural patterns are presented that need to be continued by the children. Patterning task performance has been observed to be related to mathematical competencies (Burgoyne, Malone, Lervag, & Hulme, 2019; Fyfe, Evans, Matz, Hunt, & Alibali, 2017; MacKay & De Smedt, 2019), but it is unclear to what extent the involved processes are specific to the domain of mathematics or rather reflective of fluid intelligence.

Thus, there are several early numerical abilities that are predictive of individual differences in mathematical development in the lower-to-average performance range that can therefore be considered as indicators of the potential to acquire mathematical competencies. Practically all of them can be assessed quite easily using paper-and-pencil or computerized measures. Many of these measures have been designed for detecting early numerical deficits in children that may point to an atypical mathematical development. It is an open question, however, whether high levels in these basic numerical abilities are indicative of high achievement in mathematics beyond domain-general abilities.

Competence. An essential step in the development of mathematical competencies is the acquisition of procedural knowledge of how to solve arithmetic problems and declarative knowledge of arithmetic facts (e.g., the multiplication table). Although children with dyscalculia have severe difficulties in acquiring this knowledge (Geary, 2013), children with high mathematical potential can be expected to perform exceptionally well in arithmetic. Krutetskii and colleagues (1976) observed that mathematically gifted children in primary school are characterized by strong mathematical interest and propensity to calculate and compose arithmetic problems. At higher grades (from the end of primary school on), Krutetskii et al. found gifted children to differ from non-gifted children in several cognitive processes during mathematical problem solving, including, for instance, the ability to grasp the formal structure of the problem, to generalize and remember mathematical content, or to flexibly switch between mental processes.

These and other processes were assumed by Krutetskii et al. (1976) to be closely interrelated and to form a specific property of high mathematical potential: the *mathematical cast of mind*. Mathematically gifted children "see the world 'through mathematical eyes'" (Krutetskii et al., 1976, p. 302); that is, they perceive and interpret the environment through the lens of logical and mathematical categories. This cast of mind allows them to acquire mathematical knowledge faster and attain higher levels of mathematical performance. In addition to this cast of mind, creativity has been regarded as another important component of high mathematical potential (Mann, 2006). At this level of talent development, students' creativity is evaluated "in relation to their previous experiences and to the performance of other students who have similar educational histories" (Leikin & Lev, 2013, p. 185). McMullen et al. (2016) developed an adaptive number knowledge task that draws on divergent thinking in arithmetic and, thus, captures some part of mathematical creativity at this level.

Recent empirical research has largely focused on associations between mathematical competencies and domain-general abilities. In sum, it has been found that higher competencies are associated with higher information processing speed (Passolunghi & Lanfranchi, 2012), larger short-term and working memory (Berg & McDonald, 2018; Peng, Namkung, Barnes, & Sun, 2016), higher executive functions (Abreu-Mendoza, Chamorro, Garcia-Barrera, & Matute, 2018; Bull & Lee, 2014), enhanced logical reasoning abilities (Attridge & Inglis, 2013; Morsanyi, Devine, Nobes, & Szucs, 2013), and better visuo-spatial abilities (Benbow & Minor, 1990; Frick, 2018). A review article by Myers, Carey and Szucs (2017) showed that these general correlates of mathematical competencies can also be regarded as characteristics of mathematically gifted individuals, even though the authors also noted that the current body of evidence is too limited to draw strong conclusions on this issue.

Likewise, the relevance of domain-specific and domain-general abilities for the prediction of later expertise development has been investigated only in very few studies. The largest and most prominent research project in this context is the Study of Mathematically Precocious Youth (SMPY; Lubinski & Benbow, 2006), which revealed that very high levels of domain-general reasoning abilities in adolescents transform into exceptional academic achievements in adulthood. For attainment in the mathematical domain, a specific ability profile of high visuo-spatial and mathematical abilities turned out to be predictive (Wai, Lubinski, & Benbow, 2009). Research findings on child prodigies in mathematics add to this body of evidence by showing that these children score very highly on tests of general intelligence, visuo-spatial abilities, and working memory (Ruthsatz, Ruthsatz-Stephens, & Ruthsatz, 2014).

Similar to other talent domains, psychosocial factors can be expected to loom large in the acquisition of mathematical competencies. This holds particularly true for intrinsic motivation and persistence (Subotnik, Pillmeler, & Jarvin, 2009). The amount of empirical research on this topic, however, is rather limited. In the review article by Myers et al. (2017), for instance, only one study was reported in which mathematically gifted high school children were found to exhibit a higher drive to succeed and a different pattern of interests (less interest in social, interpersonal, or religious issues) compared to a control group (Kennedy & Walsh, 1965). In sum, high mathematical competence at this developmental level should be reflected in high levels of mathematical performance, specific problem-solving processes, and the production of (relatively) original mathematical ideas. These domain-specific characteristics are complemented by high levels of cognitive functioning (general and visuo-spatial intelligence) and motivational factors.

Expertise. According to traditional expertise research (Ericsson & Lehmann, 1996; Ericsson, Nandagopal, & Roring, 2005), mathematical expertise can be defined as consistently superior achievement, which is based on an extensive domain-specific knowledge base. This is built up over several years of intensive engagement, which requires extraordinary levels of intrinsic motivation and persistence. The current empirical evidence corroborates the requirement of high levels of motivation and persistence in order to intensively engage in this domain over a long time (Subotnik et al., 2009), and, very recently, some features of deliberate practice in mathematics have been explored (Lehtinen, Hannula-Sormunen, McMullen, & Gruber, 2017). In contrast to the talent domains, chess and music (Hambrick et al., 2014), however, there are no data yet on the importance of deliberate practice for expertise development in mathematics.

There seems to be consensus that mathematicians doing research can be considered as experts. They "ask questions, raise conjectures, discover new mathematical theorems, invent new mathematical concepts and tools and prove or refute previously raised but unproved mathematical conjectures" (Leikin, 2014). Previous studies suggest that they differ from non-mathematicians in both domain-general and domain-specific ability factors (for a recent overview, cf. Sella & Cohen Kadosh, 2018). First, expert mathematicians – similar to academics in other areas – display above-average levels of general intelligence (Wai, 2014). In addition, evidence from the SMPY and other studies indicates high levels of visuo-spatial abilities (Wai et al., 2009). Both findings hold true, however, only for research mathematicians but not for calculation experts whose expertise lies in solving specific arithmetic problems (Butterworth, 2006).

Second, there is some research showing that mathematicians not only excel in high-level mathematical tasks but also in more fundamental domain-specific processes. They outperformed controls in computational estimation tasks by flexibly applying appropriate calculation strategies (Dowker, 1992; Dowker, Flood, Griffiths, Harriss, & Hook, 1996; Obersteiner, Van Dooren, Van Hoof, & Verschaffel, 2013), in a numerical agility task requiring flexible use of arithmetic knowledge (Sella, Sader, Lolliot, & Cohen Kadosh, 2016), and even in basic numerical tasks drawing on cardinality processing (Castronovo & Göbel, 2012). In addition, their numerical representations may be more abstract or spatially more flexible (Cipora et al., 2016). These findings suggest that some fundamental numerical-mathematical processes may still be particularly pronounced in expert mathematicians (see also, Amalric & Dehaene, 2016), which is in line with the view that a mathematical cast of mind is a defining feature of achievement potential in this domain. Finally, at the level of expertise, mathematical creativity becomes even more important (Sriraman, 2008). Taken together, there is some research that reveals specific cognitive profiles of expert mathematicians and that corroborates the importance of motivational factors and creativity for reaching this developmental level.

Transformational achievement. At this level, individual mathematical expertise is expressed in creative accomplishments that are considered as major or ground-breaking by the scientific community. Psychological research on predictors for achieving this level is practically non-existent. There are some qualitative and biographical studies involving eminent mathematicians (e.g., Kolata, 1987; Simonton, 2004), which generally emphasize the significance of the factors that turned out to be important for the previous level (in particular a mathematical cast of mind, creativity, motivation and persistence). For instance, in the most recent study of this kind, Mehta, Mishra, and Henriksen (2016) reviewed information on the four 2014 Fields Medal winners (the mathematicians' "Nobel Prize") and observed that all of them reported to see mathematics everywhere, to be driven by creative avocations and aesthetic aspirations, and to have a strong personal relationship to the domain.

Gaps in the literature and a future research agenda. Talent development in mathematics appears to be a research field with numerous open questions in all four levels of the TAD framework. At the aptitude level, the research focus needs to be extended from the lower-to-average to the high performance range. In particular, it is unclear whether and to what extent basic numerical abilities are indicators and predictors of high mathematical achievement. In the development of mathematical competence, very little is known about the interplay of domain-specific and domain-general factors for knowledge acquisition and performance. This particularly applies for the relation of the mathematical cast of mind and intelligence as well as psychosocial factors. Finally, in contrast to other expertise domains (e.g., music, chess), there is a lack of research on the development of mathematical expertise and creative productivity. Specifically, the importance of deliberate practice, domain-relevant experience, and psychosocial skills is largely unknown. Further, there is a lack of research explaining specialization processes, although there is evidence for the important role of ability-personality profiles for domain selection and creative productivity in mathematics (Lubinski, 2016).

Music

Music is a domain that presents an almost paradoxical situation with regards to talent development. On one hand, there are widely cited models of musical talent development (e.g., Davidson & Faulkner, 2013; Gagné, 2008; Kirnarskaya, 2009), there is widespread use of teacher checklists for talent identification (Heller & Perleth, 2008; Ohio Department of Education, 2009; Wisconsin Music Educators Association, 2009), and a long tradition of perceptual tests that purport to measure musical talent (Bentley, 1966; Gordon, 1989; Seashore, 1919; Wing, 1968). On the other hand, musical talent models like the one suggested by Gagné are not specified at a level that would allow empirical validation and there is a lack of convincing evidence for any predictors of musical talent to have substantial predictive power for future musical success (e.g., Howe, 1998; Manturzsewska, 1990; Norton, Winner, Cronin, Lee, & Schlaug, 2005).

A primary reason for the lack of an empirical model of musical talent development is the scarcity of longitudinal studies that would provide the data necessary for specifying and testing such models. Longitudinal studies are complex (Little, 2013) and expensive to run. Hence, the few longitudinal studies in the music research literature do not make use of a comprehensive quantitative assessment approach, but rely largely on qualitative research techniques (e.g., McPherson, Davidson, & Faulkner, 2012; Sloboda & Howe, 1991) or use only small samples with a normal distribution of musical abilities, thereby lacking a specific focus on high achievements or accelerated musical development (Gordon, 1975).

In addition, the decision to end formal musical training and to change career focus despite a promising trajectory is common in musical careers (McPherson et al., 2012). It is possible that limiting the definition of expertise and success to achievements as a musical performer is too narrow, given the few opportunities to make a successful living as instrumentalist compared to many other professional career options in music. This concern is particularly salient in the realm of Western art music (Simonton, 1991), the primary subject of academic studies of musical talent as well as talent identification checklists.

Another problem for the identification of quantitative indicators of musical talent is the often implicit assumption that quantitative features such as intelligence and working memory (Hansen, Wallentin, & Vuust, 2013), emotional engagement with music (Kirnarskaya & Winner, 1997), musical discrimination ability and musical memory (Gordon, 1986) assessed at an early age can serve as predictors for musical long-term development. However, the failure to identify long-term indicators of musical achievement so far seems to suggest that psychological variables assessed at an early age are predictive of the development of musical skills at early levels of development but have less predictive value for later developmental levels (or, alternatively, that suitable long-term predictors are still waiting to be discovered).

The TAD framework has several features that address these difficulties and, therefore, holds the promise to provide the necessary theoretical orientation for the development of an evidence-based model of musical talent that allows for rigorous empirical testing ~~(including potentially falsification)~~ as well as providing useful predictions for the musical trajectory of individuals. First, it focuses on measurable psychological constructs. Second, by breaking up the developmental trajectory into different levels, models from the TAD framework do not rely on the assumption that individual psychological variables need to have strong predictive power across long periods of musical development. Further, the four developmental levels of the TAD can be closely linked to Levels I to IV in Manturzewska's (1990) model of lifespan development of professional musicians that she developed from a large interview study with professional as well as artistically eminent musicians. Third, in line with the concept of musical sophistication (Müllensiefen, Gingras, Musil, & Stewart, 2014), the TAD framework does not prescribe only a single prototypical musical trajectory (e.g., as performer of Western art music), but also allows for considering high musical achievements in other forms, including music composition or production and in genres other than Western art music.

Aptitude. Within the TAD model of music development, high musical aptitude is defined as general mental and physical potential to process, learn, and produce music at a high achievement level in the future. Therefore, musical aptitude is developed before the start of any systematic music instruction, that is, the first course of systematic music instruction received from a teacher or the initial phase of self-directed music learning. Moreover, the term aptitude describes the *potential* to go through the initial levels of systematic music learning. High musical aptitude would be predictive of measureable high musical achievements after an initial learning phase (i.e., after a few music/instrumental lessons or after a few sessions of self-directed music learning). For musicians engaged in Western art music, the start of systematic music instruction is often between 5 and 7 years. However, for many self-taught musicians within the popular music genre, the start of systematic music learning can be much later, for example, between 10 and 15 years. Consequently, the TAD framework avoids any general association of windows of chronological time with developmental levels.

According to the literature, general psychological features that might be linked to high musical aptitude and short-term musical achievements are intelligence (Schellenberg, 2011), working memory (Vandervert, 2016), and basic motor skills relevant for the particular form of instrumental learning. In addition, skills associated with high aptitude that are thought to be music specific include sensory sensitivity and emotional understanding of music (Kirnarskaya & Winner, 1997); cognitive auditory skills, including sequence memory and perceptual discrimination skills (Gordon, 1986); singing ability (Howe, Davidson, Moore, & Sloboda, 1995); rhythmic skills (Kirnarskaya, 2009; Zuk, Andrade, Andrade, Gardiner, & Gaab, 2013);

and the development of musical imagination and spontaneous musical activity (Manturzewska, 1990).

To validate a predictive model, these general psychological as well as music-specific variables should be assessed ideally before the first music lesson or first self-directed music session. Subsequent achievement should be assessed after a period of several sessions. Achievement can be determined through structured reports from multiple observers (e.g., instrumental teacher, class teacher, parents, peers) following the guidelines suggested by Haroutounian (2000). In addition, the development of music perception abilities can also be measured via an increase in tonal, rhythmic and harmonic abilities on standardized listening tests. Musical achievements after this early music learning phase should reflect the ability to benefit from instruction and feedback, the cognitive and sensory-motor mastery of basic musical elements, the command of means of musical expression (i.e., dynamics and articulation), the ability to combine mastered elements to more complex musical objects, and the ability to self-learn and self-correct during music production to a certain degree. In sum, musical aptitude according to the TAD framework comprises psychological factors that are beneficial to the first stage of musical learning and permits the prediction of musical achievements after units of initial instruction or self-directed teaching.

Competence. Musical competence describes the cumulative acquisition of skills necessary for widening the musical repertoire of music as well as the range of expressive scenarios and musical contexts that an individual can contribute to. For music performers, developing competence includes the mastery of increasingly complex pieces and the ability to perform in different settings (e.g., solo, together with other performers, or as part of an ensemble or a band) and to change expressivity at will and independent from musical structure.

Competence also includes the cognitive and perceptual recognition and processing of complex regularities in musical structure. In addition, the ability to make independent aesthetic and creative decisions and execute these also ranks among the achievements at the competence level. Depending on the genre of music, competence includes an understanding of harmony, rules for the generation of melodic lines, complex rhythmical patterns, the links between emotional expressivity and sound texture and dynamics, as well as the rules for the interaction of multiple voices and instruments.

These achievements can be assessed through structured reports by multiple observers (Haroutounian, 2000) and—depending on the ability to verbalize introspections of the music learner—through self-report. The features frequently suggested as beneficial for high achievement at the competence level are a growth mindset (Dweck, 2000; Müllensiefen, Harrison, Caprini, & Fancourt, 2015); the ability to self-motivate, a positive musical self-concept (Spychiger & Hechler, 2014); the integration of musicality into self-concepts (Müllensiefen et al., 2015); motor skills (Kopiez & Lee, 2006); teachability; the ability to cope with failure; self-motivation to learn (Jarvin & Subotnik, 2010); and the "rage to master," a high level of intrinsic motivation to perform exceptionally well in the domain (Winner, 1996).

The transition from aptitude to competence level is continuous and hence there is no clear starting point for the competence level. However, most authors (Gembris, 2009; Maturzeswka, 1992) agree that time deliberately (and without external pressures) invested into musical learning is an indicator. Hence, the beginning of the competence level could be defined as the point in time where a substantial increase in the time dedicated to musical learning is discernible. Taken together, the competence level is the stage where an individual masters increasingly complex musical materials as well as broadening the musical repertoire and expressive scenarios to a considerable degree. The increased competence is reflected in the cumulative acquisiton of necessary skills which goes in hand with a substantial increase in the time deliberately dedicated to musical learning.

Expertise. With regards to musical development~~al~~, expertise might be characterized by a superior level of musical skills that is recognized by peers and allows an individual to act within professional contexts. In the music domain, expertise can be indicated for example by regular performances for larger audiences or the regular production of music or the engagement of music-related activities for the benefit of an audience (producing, editing, writing about music, teaching, selecting music for commercial situations). Achievements at the expertise level might be measured by the number, frequency and complexity, quality, creativity and diversity of performances, musical productions, or music-related products. Although number and frequency of musical productions can be easily measured objectively, judging the complexity, quality, creativity, and diversity will usually require some form of peer expert judgement.

The transition from the competence to the expertise level is also a continuous process and marking the starting point of the expertise level for the assessment of psychological features is difficult. But part of the expert status is the recognition that an individual's work reflects a strong grasp of the domain such that the performer is capable of generating good solutions to important domain problems (Subotnik et al., 2019). Therefore, an indicator of expertise can be the marked increase in time invested in outward facing musical activities compared with private musical engagement such as deliberate practice and exercising.

Features considered relevant for the development of musical expertise that should be assessed at the beginning of the expert level include relative psychological stability, openness to experience, conscientiousness, resilience, obsessiveness (Winner, 1996), rational deployment of time as well as mental and monetary resources, and the ability for critical but constructive judgement of one own's work (Sternberg, 1999). In summary, the level of musical expertise is often characterized by the increasing amount of musical activity that is outward facing and directed towards an audience. Musical experts are usually able to act within professional contexts and to provide good solutions to difficult musical problems that are recognised by their peers.

Transformational achievement. Musical achievements at the level of creative productivity are characterized by the volume of professional artistic output, commercial success, artistic recognition from expert judges and a wide audience, the influence on other musicians, and the freedom to make aesthetic and creative choices at the highest level. Predictors for achievements at this level include the ambiguous attribute, charisma, as well as other factors that are only partially psychological (Jarvin & Subotnik, 2010). Chance and context can be equally important factors for creative productivity, which include opportunities and events that are outside an individual's control. Hence, statistical modelling of high musical achievements at this level might not be feasible because of the large number of potential predictors and the difficulties associated with their measurement.

In addition, the data available on individuals working in the musical domain at the creative productivity level will be small. Therefore, qualitative research (Folkestad, 2004), descriptive statistics (e.g., Simonton, 1977, 1996), retrospective self-reports (Krampe, 1994, 2006) or biographical studies (Manturzewska, 1992) might be more appropriate at this level. Hence, creative producitivity and sustained contributions to the musical world are hallmarks of the highest level within the TAD framework. At this level, factors such as a chance, charisma, and aesthetic choice might be factors that are at least equally responsible for achievements as are psychological constructs.

Gaps in the literature and future research agenda. The descriptions of the four developmental levels highlight the core principle of an empirical implementation of the TAD model: Future musical achievements at the end of a developmental phase or broader developmental level are predicted from the level of current musical achievements and from a set of psychological features. Hence, the main task for the construction of an empirical test of the TAD model is to define suitable assessment measures of musical achievement and sets of psychological features that might have predictive power for specific levels and phases of musical development. However, what suitable assessment measures and psychological features are depends massively on the musical genre, the type of music education, and the age range of participants observed. Therefore, assessment measures and psychological variables can only be chosen within the context of specific study and not a priori and in a blanket way. Although the degree of musical aptitude for initial music learning can be assessed in a large proprotion of the general population, fewer and fewer individuals will develop to obtain musical competence and expertise; and only a tiny fraction will be able to make a transformational achievement to the music world. Hence, suitable assessment will need to reflect this increaing specialization of the population under study.

In any case, the most principled way of testing the TAD framework empirically is the analysis of longitudinal data over a specific period (e.g., kindergarten time, primary school years or adolescence) that allows for the comparisons of musical achievements at later time points with achievements and psychological profiles at earlier points in time. The implementation of such a study is a primary item on the future research agenda for the TAD model in music.

Visual Arts

Contemporary visual art is an ill-defined and varied domain, encompassing a wide range of styles, activities, and media—many with only a tenuous link to traditional modes of naturalistic depiction. This social reality greatly complicates ecologically valid considerations of talent development in visual art (especially at its more advanced levels), but its initial manifestations still tend to involve the activity of drawing and the progressive mastery of realism. That said, the research literature on talent development in visual art is thinner than in music or mathematics, but there are still some useful guideposts for measureable predictors and indicators oft talent development.

Aptitude. In visual art, early forms of aptitude typically refer to realistic drawing performance, rather than evidence of creative expression. All normally developing children draw. Moreover, they evince a well-established progression of stages of childhood drawing (Kerlavage, 1998; Lowenfeld, 1947/1982; Luquet, 1927/2001). Children between 1 year and 3 years old scribble with no concern for representation. Between ages 3 and 4, they enter a *preschematic* stage, drawing more intentional shapes and lines and designating the marks as particular objects; the simple "tadpole" figure representing a person is emblematic of this stage. By 5 or 6, children reach a *schematic* stage, demonstrating more control over drawn shapes coupled with an assimilation of culturally prevalent schemas for representation, like depicting a house by a triangle atop a square. By 7 or 8, children start to be more critical of their own work, and by age 10 or so, without proper instruction and encouragement, many will stop drawing altogether.

As summarized by Winner and Drake (2013), aptitude for visual art is evident in several developmental qualities that are characteristic of precocious young artists. First, they learn very rapidly in the domain, passing through the same sequence of stages as other children, but doing so notably faster. Indeed, their depictions are typically advanced by at least several years beyond their non-precocious counterparts. They may draw recognizable shapes and differentiate basic body parts by age 2, use fluid contour to outline complex shapes, draw objects in noncanonical orientations, add rich detail, and suggest depth by the full range of historically hard-won techniques of Western artists: foreshortening, occlusion, size diminution, shading and modeling, and linear perspective. Drawing prodigies also show a high level of intrinsic motivation to perform exceptionally well ("a rage to master") and thus work compulsively, needing no outside encouragement. Precocious artists also make discoveries through self-teaching and they can do things, like employ a complex but accurate fluid contour line beginning at any part of an object or vividly recall something previously seen, that are *never* mastered by ordinary children. Even by age 5, some prodigies are drawing at a level considerably more sophisticated than most adults.

A more specific psychological basis of prodigious (or even well above-average) childhood performance in drawing remains elusive, as few researchers have examined this issue in detail. There is some empirical evidence that such children have a bias toward processing local details (that is, being able to draw details without the distraction of the broader context; Drake, Redash, Coleman, Haimson, & Winner, 2010; Drake & Winner, 2011). Several other markers for precocious drawing skill have also been identified, including a higher-than-average incidence of non-right-handedness (Mebert & Michel, 1980), linguistic deficits like dyslexia (Gordon, 1983), and poor stereopsis (depth perception produced by the brain receiving input from both eyes; Livingstone, Lafer-Sousa, & Conway, 2011). Also, adult artists often anecdotally report having been intently involved with visually analyzing the world at young ages

(Schlewitt-Haynes, Earthman, & Burns, 2002), a visual analog, perhaps, of spontaneous focusing on patterns or numerosity among budding mathematicians. More broadly, Gardner (1973) speculated that young artists "may be characterized … by greater sensitivity to sensory stimulation and to the works of others; usual capacity for awareness of the relationship between stimuli; heightened fluency of ideas; predisposition to an empathy of wide range; and keen and agile sensorimotor equipment" (p. 256).

This last set of possibilities highlights the complexities inherent in early artistic talent development. It also raises a common theme in identifying talent in achievement domains: the extent to which early aptitudes reflect domain-specific versus domain-general capacities. This question is a significant issue in visual art, because realistic drawing requires the artist to solve the same kinds of problems as the visual system does generally, with a concomitant need for flexibility in processing (Kozbelt & Ostrofsky, 2018). Relatedly, just as aspects of mathematical reasoning may overlap with broader visual-spatial ability, the same may be true of drawing, in that a broader comprehension of spatial relations or quantitative reasoning may be useful for (and in turn benefit from) other aspects of the activity of drawing. Finally, it remains unclear how any predictors that are useful for identifying artistic talent in young children may or may not continue to hold in later years, as additional competence and expertise accrue.

In sum, drawing talent often manifests itself very early. Because virtually all children draw, and the features of their depictions unfold in a predictable agewise sequence, precocious artists may be readily identified by their accelerated development, very high intrinsic motivation, and mastery of complex depictive techniques. Certain biological markers, including perceptual strengths like a bias toward local processing, have been tentatively identified as supporting prodigious artists' abilities.

Competence. Although most children stop drawing regularly by age 10 or so, those who have some talent often persist, and they continue to improve in their realistic depiction ability as well as artistic originality. Much more empirical research has been conducted on differences between artists and non-artists in this regime of talent development, which may be said to extend to the age where a budding artist has made a career commitment to the domain, usually by enrolling in post-secondary-level (that is, college) art training. In terms of education and career development, many future artists pursue such training, though curricula vary widely across different institutions and programs.

A major focus of this line of research has been on the constellation of perceptual strengths that are associated with drawing skill. These mainly appear to involve top-down attentional control and high-level object understanding and visual analysis. Specifically, artists show perceptual advantages on tasks involving visual memory and mental rotation ability (Perdreau & Cavanagh, 2015; Winner & Casey, 1992), object recognition (Kozbelt, 2001; Kozhenikov, Blazhenkova, & Becker, 2010), dis-embedding complex figures (Chamberlain et al., 2019; Kozbelt, 2001), enhanced efficiency in the perceptual processing of objects (Perdreau & Cavanagh, 2014), more astute selection of important visual features (Kozbelt, Seidel, ElBassiouny, Mark, & Owen, 2010; Ostrofsky, Kozbelt, & Seidel, 2012), and enhanced flexibility in shifting attention between the global and local aspects of a stimulus (Chamberlain & Wagemans, 2015; Perdreau & Cavanagh, 2013) or between different interpretations of a bistable figure (Chamberlain et al., 2019). And although the evidence is not always consistent, artists' advantages do not appear to extend to lower-level processes like perceptual grouping (Ostrofsky, Kozbelt, & Kurylo, 2013), overcoming perceptual constancies (McManus, Loo, Chamberlain, Riley, & Brunswick, 2011; Ostrofsky et al., 2012; Perdreau & Cavanagh, 2011), or visual illusions (Chamberlain & Wagemans, 2015).

Several studies (Chamberlain et al., 2019; Kozbelt, 2001) have found that artists' perceptual advantages can justly be regarded as largely a subset of their drawing advantages. This finding implies that perceptual advantages are developed mainly to the extent that they are useful in drawing, in turn suggesting a developmental interplay between drawing and perception. Very little longitudinal research has directly pursued this question, however, so the psychological and perceptual dynamic of talent development, as visual artists develop competence in their domain, remains mysterious. Beyond refining perceptual skill and gaining domain-specific skills and knowledge, visual artists continue to develop a growing repertoire of techniques to describe their understanding of themselves and their world, using art-making to navigate complex issues of identity formation in adolescence, within their sociocultural context (Burton, 1981; Gude, 2007).

In sum, the development of artistic competence—as a talented child transitions into a nascent professional artist—is accompanied by the development of greater artistic skill as well as additional perceptual strengths, which have been examined in many empirical studies. Although many of these skills are beginning to be understood, many questions about their longitudinal development and relation to each artist's emerging creativity, style, and sense of self-identity remain unanswered.

Expertise. The later levels of talent development in visual art are more elusive and fraught than earlier levels, and much less research has attempted to disentangle their various strands. The most well-established research traditions on talent and visual art, described above—such as the typical stages of drawing development and precocious drawers' divergence from it, or the nature of artists' perceptual advantages—may simply not be very relevant for high-level artistic expertise or achievement in the contemporary world. Indeed, irrespective of whether or not a post-secondary-level studio art program emphasizes realistic drawing skills, other aspects of the activity of art-making appear to be very important in order for a budding artist to "make it" as a professional. Undergraduate-level (BFA) or graduate-level (MFA) training in visual art is not nearly as rigorous or uniform as in other aesthetic domains like music or dance.

Moreover, the very process of art education, and its purported payoff for professional advancement, is not well understood – witness the pessimistic title of James Elkins' (2001) book on art schools, *Why Art Cannot Be Taught*. At the very least, as Sawyer (2006) noted, "even if art schools don't teach one how to make art, we know that they can teach one how to talk like an artist, how to write like an artist, and how to participate in the art world" (p. 188). In sum, an ecologically valid characterization of artistic expertise, and its relation to earlier stages of talent development described above, remains elusive—perhaps because in practice these levels are more dissociated than in better-structured domains, with less predictability in who will successfully manage the transition.

Transformational achievement. Regardless of attained competence or expertise, for a person to maintain a status as a full-time professional artist in the modern world, many things have to go right. Successful artists may show high levels of grit and other motivational factors (Duckworth, 2016), but chance factors (see Simonton, 1999) and socio-cultural aspects of creativity like gatekeeping (Csikszentmihalyi & Csikszentmihalyi, 1988; Subotnik et al., 2019) are probably important in inducing a very high attrition rate, whereby few individuals are ultimately able to support themselves entirely by a career creating visual art.

Tied to this reality, the concept of creativity as inherent to visual arts practice is very important—indeed, visual art remains probably *the* paradigmatic domain for creativity, generally (Sawyer, 2006). Research on the creative process in artists suggests that some modes of creativity are more likely to lead to career success. For instance, a greater willingness to engage in problem finding behavior, in not settling for easy solutions, and continuing to opportunistically revise an emerging artwork (Getzels & Csikszentmihalyi, 1976; see also Dudek & Côté, 1994; Kozbelt, 2008) was associated with success in the art world some years later (see also Csikszentmihalyi & Getzels, 1989). Other scholars have suggested multiple paths to real-world creative success, including not only exploratory problem-finding but also high-level conceptual innovation (Galenson, 2001, 2006), or artists banding together into collective movements (Accominotti, 2009), or sensitivity to the predominant socio-cultural milieu (Sawyer, 2006), which may fluctuate between valuing different modes of creativity.

In sum, as with higher-level, artistic education, professional, real-world creativity in visual art remains a woefully understudied phenomenon, particularly from the standpoint of talent development and what could be done to help guide promising artists toward success. Any advances in our knowledge are likely to remain provisional, given the ill-defined and shifting nature of the domain itself.

Gaps in the literature and future research agenda. As the preceding discussion suggests, many themes and aspects of the trajectory of talent development in visual arts are not well understood. Basic research to fill in these lacunae would be useful, but even then the nature of the domain itself is a complicating factor for our understanding. Among the issues to be addressed are the following. For aptitude, it would be useful to develop a richer sense of perceptual antecedents and associates of outstanding early drawing skill, as well as a more inclusive sense of early artistry, not limited to realism. Better understanding competence would result from continued research on perceptual correlates of outstanding drawing skill, including more longitudinal studies and research on neural substrates, motoric aspects of drawing, and their relation to expressions of artistic creativity. For expertise, a far more complete understanding of the nature and utility of college-level training in art would be beneficial.

Analogously, for transformational achievement, a richer characterization of the necessary skill set for navigating the professional art world, including aspects like the nature of gatekeeping, would be tremendously informative. For both expertise and transformational achievement, a more detailed sense of how perceptual advantages and other factors that are demonstrably important at the aptitude and competence levels continue to influence later levels (or not) would be helpful. At all levels, the particular, highly domain-specific and idiosyncratic aspects of creative expertise in visual art are not well understood – particularly how they emerge from the fairly domain-general constellation of competencies characteristic of younger artists.

Conclusion

The TAD framework provides a general talent development framework applicable to a wide range of achievement domains. The overarching aim of this framework is to support empirical research on talent development in different domains by (a) offering a common basis of concepts and definitions that can be used across several domains, (b) focusing on measurable psychological constructs and their meaning at different levels of talent development, and (c) integrating the internal processes that lead to becoming interested and successful in a domain. Compared to its springboard, the megamodel by Subotnik et al. (2011), the TAD framework puts a stronger focus on the role of internal psychological variables and processes that are related to talent development. Further, whereas the megamodel emerged from a descriptive synthesis of the literature, the TAD framework can be used to guide such a synthesis. In a first step, for each domain, empirical evidence for increasing specialization and level-dependent predictors and indicators of talent development can be reviewed to build a domain-specific, talent development model. In a next step, open questions and research gaps can be identified according to the model. And finally, specific predictions about talent development in a specific domain can be derived from the model and empirically tested.

We provided examples for the application of the TAD framework to the domains of mathematics, music, and visual arts. The empirical evidence clearly shows that the process of talent development varies by domain, even though several cross-domain similarities could be identified. For example, talent development starts early in all three domains (i.e., in the pre-school years). At the *aptitude* level, all domains list general cognitive abilities (i.e., working memory, reasoning or fluid intelligence) as predictors of aptitude and precocity, engagement, and the ease or speed of learning as indicators. Further, domain-specific, attentional information processing seems to be relevant in all domains (e.g., a spontaneous focusing on domain-relevant stimuli like numerosity, rhythm, or visual details) as well as the motivation to proceed with domain-specific tasks and challenges. Differences among domains can be found, for example, in the role of motor abilities which are highly relevant for drawing and playing an instrument but which are less important for mathematics. Another example refers to self-teaching. Although it seems to be a precditor of talent development in the domains of music and the visual arts, its role is unclear for the domain of mathematics.

At the *competence* level, findings from all three domains suggest the developmental interplay between the person and the demands and features of a domain suggested by the TAD framework. That is, although general cognitive ability still represents a predictor of talent development, domain-specific, cognitive skills that in part result from engagement in a domain gain importance (e.g., procedural and declarative knowledge about arithmetics, musical structure, or visual perspectives). Further, all three domains list creativity and mental flexibility as predictors of talent development. In addition, motivational variables like intrinsic motivation and interest are still relevant, and personality variables such as conscientiousness become even more relevant for talent development in all three domains as they support learning and engagement. Overall, talent development at the competence level shows many similarities across domains: although contents differ, learning and skill acquisition, creativity, and motivation are central in all domains.

Findings for the *expertise* level are scarce in all three domains, which points to common research gaps regarding, for example, the relative importance of general as compared to more specific cognitive abilities, the relevance of indicators of talent development at the competence level for high achievement at the expertise level, or specificities of ability-personality profiles of experts in different domains. The same applies to the level of *transformational achievement*. Although case studies emphasize factors like creativity, persistence, or psychological strength, there is an overall lack of research on the development of expertise and transformational achievement during later periods.

These research gaps in all three domains further reveal the need for longitudinal studies that illustrate developmental changes in all these domains. In addition, there is a lack of assessment instruments suited to capture talent development in sub-fields of a domain (e.g., in the domain of music, for music composition, arrangement, selection, production, communication etc.). Finally, with increasing levels of talent development, the number of persons decreases while predictors of talent development might become more idiosyncratic (Simonton, 1999).

Hence, statistical modelling of high achievements at this level might not be feasible, but more retrospective (interview) studies, qualitative research, or quantitative single-case research designs might be more appropriate at this level.

Overall, the review provided for the three domains indicates numerous research gaps and open questions that should be addressed in future research. The TAD framework identifies many of these open questions and has the potential to answer some of them by bringing together the knowledge base from different domains, by structuring it according to the four levels of talent development, by comparing predictors of talent development within and across levels or domains, and by formulating common research questions that should be addressed in future studies.

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Footnotes

While taking a psychological perspective, we acknowledge the importance of contributions from other disciplines like philosophy, sociology, history, or economics for understanding achievement and its development. We are aware of the need to discuss achievement and its development from multiple perspectives and we would be happy if the current work would stimulate such a discussion.

[2]Worrell, Subotnik, and Olszewski-Kubilius (2018) give the following definition: Eminence is the title reserved for individuals with fully developed talents who are extremely gifted in a domain relative to other highly gifted producers and performers in that domain. This relative superiority is acknowledged by the most knowledgeable members of the domain, and is typically related to a contribution or sustained contributions that have had, or will have, a lasting and memorable impact on the domain (p. 248).

[3]*Achievement domain* refers to a domain that has its own quality and evaluative criteria, its own curricula, knowledge, and skills, and expected learning outcomes of the targeted curriculum or course of study (i.e., curriculum goals, objectives, or indicators).

[4]Of note, the extent to which variation in a trait is influenced by genetic factors, on the one hand, and the extent to which that trait is modifiable, on the other, are orthogonal considerations. That is, the extent to which variation in a trait is influenced by genetic factors does not tell anything about the extent to which that trait is modifiable.

Table 1

Summary of the Main Assumptions and Research Implications of the Talent Development in Achievement Domains (TAD) Framework

The TAD Framework: Summary and Implications

Summary: The TAD framework …

- is a general talent development framework
- can be used for constructing domain-specific talent development models as it offers a common set of concepts and definitions that can be used across several domains
- originates from the talent development Megamodel (Subotnik, Olszewski-Kubilius, & Worrell, 2011):
  - It describes the talent development process at four successive levels (i.e., aptitude, competence, expertise, and transformational achievement).
  - It follows the notion of a trajectory in talent development moving from general abilities to specific skills and competencies.
  - It conceptualizes talent development as dependent on a multiplicity of factors whose relative importance can vary with level of talent development.
- has a primary *psychological focus* on (measureable) person-related variables (while acknowledging environmental and genetic factors)
- focuses on internal processes that lead to interest and success in a domain:

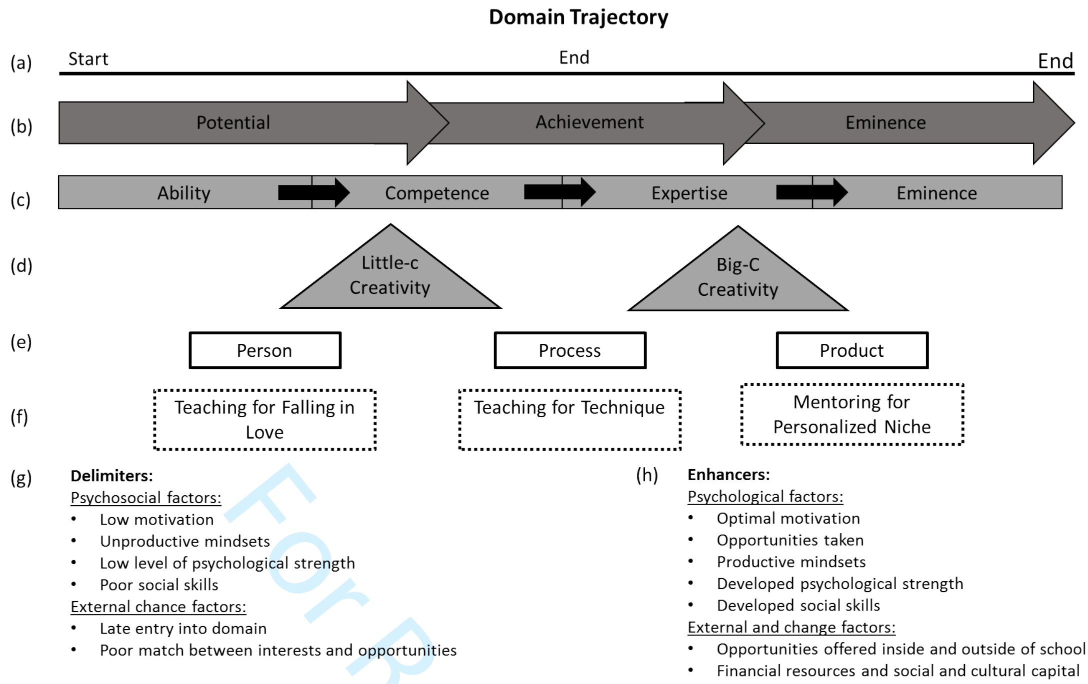
  Ability differentiation: General abilities are invested into the acquisition of specific knowledge or skills by taking advantage of learning opportunities leading to the development of more specific abilities or specialized knowledge structures.

  Interplay of ability development and personality development: Ability and personality factors develop along mutually causal lines within the process of talent development that results in specific ability-personality profiles.

  Profiles inform talent development: Ability-personality profiles are important to understand the process of specialization within talent development. Investment and success in a domain reinforce identification with the domain that, in turn, enhances investment and success.
- suggests predictors and indicators of talent development at the four different levels that can be used to identify achievement potential and to track progress in an achievement domain

Implications: The TAD framework …

- can be used to empirically identify significant predictors of talent development that differ/are comparable across different achievement domains
- suggests investigating the validity of predictors of talent development within one level and between adjacent levels more than focusing on long-term predictive validity
- defines levels of talent development in terms of positions on the developmental trajectory; it remains an open question whether and how these levels might be linked to critical time windows or age
- suggests investigating ability-personality profiles as predictors of specialization and as indicators of the readiness of an individual for what is required at the next level of talent development
- identifies open questions and reseach gaps (e.g., regarding the process of specialization)



Legend

(a) Domains have developmental trajectories with different start, peak, and end times.
(b) Giftedness in a domain is evaluated in relationship to others;
(c) initially in terms of potential, later by demonstrated achievement, and finally, in adulthood, by eminence. The talent-development process involves several transitions whereby abilities are developed into competencies, competencies into expertise, and expertise into eminence.
(d) Transitions are distinguished by levels of creativity, beginning initially with "little-c" creativity (independent thinking, entertaining different perspectives, creation of projects and products that are novel when compared to those of peers), and ultimately the "big-C" creativity required for eminence.
(e) These transitions involve shifting emphasis from "person" (creative approach and attitude) to "process" (acquiring process skills and mind sets) "product" (creation of intellectual, aesthetic, or practical products or performances).
(f) Each stage in the talent-development process is also characterized by different strategies and goals of instruction – initially to engage young people in a topic or domain ("falling in love"), then helping the individual to develop the needed skills, knowledge and values ("teaching for technique"), and finally, helping the talented individual develop their own unique niche, style method, or area of application ("mentoring for personalized niche").
(g) Movement from ability to eminence can be delimited by factors such as low motivation, mind sets that prevent coping with setbacks or thwart resiliency, less-than-optimal learning opportunities, or chance events.
(h) Progress can be enhanced, maintained, or accelerated by the availability of educational opportunities including out-of-school enrichment and mentoring, psychological and social support from significant individuals, and social capital.

Figure 1. Megamodel of talent development (from Subotnik et al., 2011, p. 34).

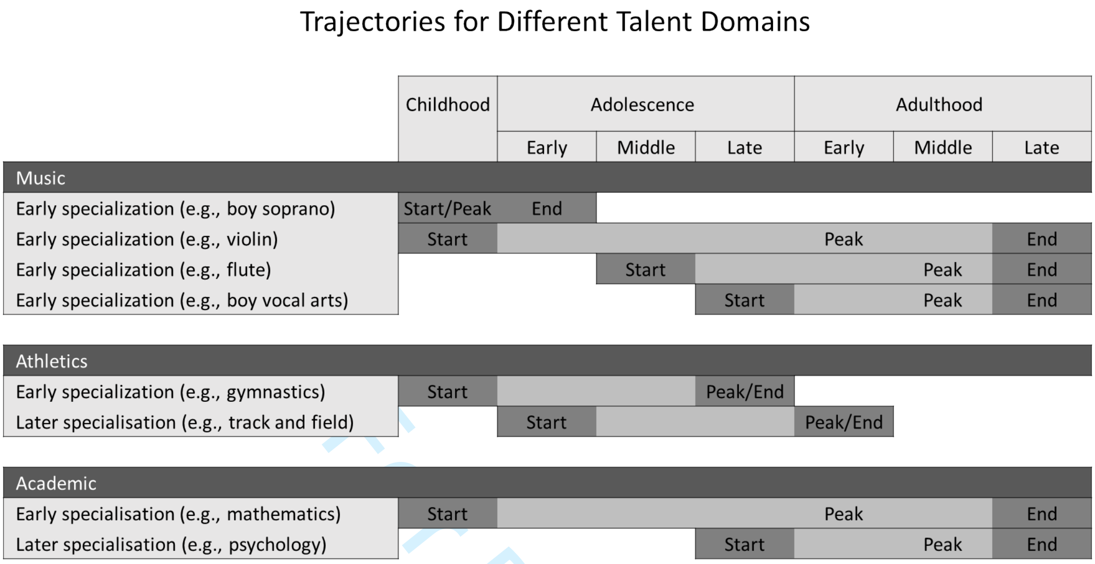
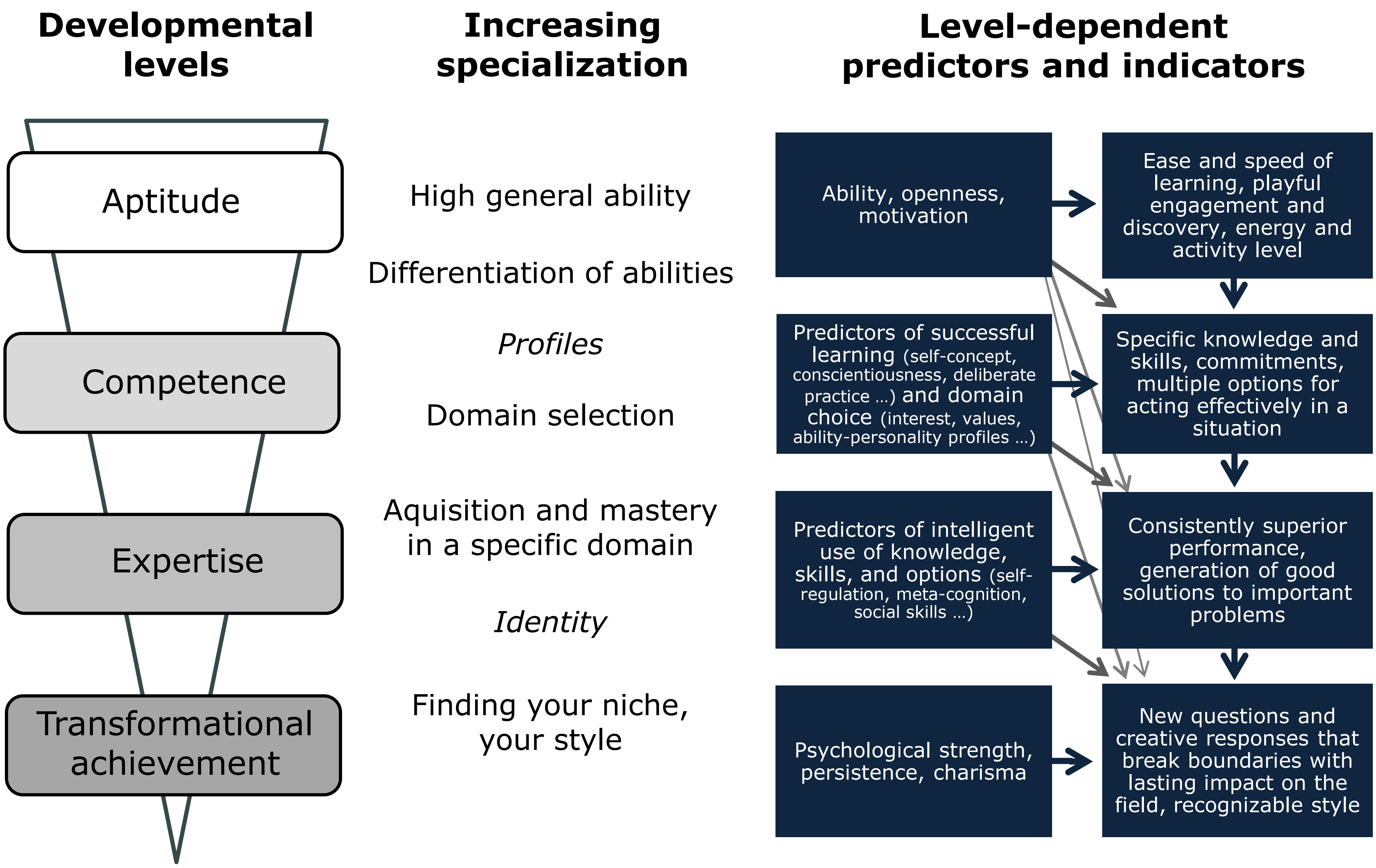


Figure 2. Early and later trajectories in music, athletics, and academics within and across domains (from Subotnik et al., 2011, p. 32).


Developmental levels
Increasing specialization
Level-dependent predictors and indicators
Aptitude
Competence
Expertise
Transformational achievement
High general ability
Differentiation of abilities
Profiles
Domain selection
Aquisition and mastery in a specific domain
Identity
Finding your niche, your style
Ability, openness, motivation
Ease and speed of learning, playful engagement and discovery, energy and activity level
Predictors of successful learning (self-concept, conscientiousness, deliberate practice …) and domain choice (interest, values, ability-personality profiles …)
Specific knowledge and skills, commitments, multiple options for acting effectively in a situation
Predictors of intelligent use of knowledge, skills, and options (self-regulation, meta-cognition, social skills …)
Consistently superior performance, generation of good solutions to important problems
Psychological strength, persistence, charisma
New questions and creative responses that break boundaries with lasting impact on the field, recognizable style