Behind An Accelerated Scientific Research Career:

Dynamic Interplay of Endogenous and Exogenous Forces in Talent Development

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Abstract

This study looks at the educational experiences, from preschool years to advanced professional training in STEM fields, of a targeted sample of 10 (7 male, 3 female) early college entrants in China who later became professors at prestigious US research universities. The purpose of the study was to find out: 1) what are some identifiable endogenous factors about this these individuals that facilitated the success of their accelerated learning and development; 2) what kinds of exogenous factors (e.g., environmental opportunities, resources, support) they experienced from childhood to adulthood; and 3) what was the long-term impact of accelerated learning and development. Central to the present study is the following overarching question: in what way do personal characteristics become developmentally instigative in terms of accelerating one's development, and in what way do exogenous factors provide optimal conditions in terms of facilitating such an accelerated developmental trajectory? Retrospective interview and biographical case investigation were used for data collection. Thematic analysis of the codes from interview data yielded a conceptual map, followed by a more up-close probing of five representative individual cases. A distinct set of endogenous and exogenous factors at different developmental junctures are identified, and their dynamic interplay are delineated to account for accelerated trajectories toward a scientific research career. Theoretical significance and practical implications of the study for talent development in science are discussed.

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Academic acceleration has drawn research attention for many decades, resulting in a bulk of empirical studies. Recently it has regained prominence as an effective way of accommodating gifted and advanced learners in school (Colangelo, Assouline, and Gross, 2004; Steenbergen-Hu, Makel, & Olszewski-Kubilius, 2016). Although there are many forms of academic acceleration, depending on developmental timing and practical circumstances, the main impetus is to provide academic challenges commensurate to more advanced levels of competence and the faster pace of learning that some students demonstrate. Based on the early research, Feldhusen, Proctor, and Black (1986) proposed twelve guidelines for procedures and criteria regarding decision-making on academic acceleration. Roger (2004) conducted a comprehensive review of research on subject-based and grade-based accelerations with K-12 students, and concluded that many forms of academic acceleration tend to produce additional growth in knowledge and skills; namely, it creates a Matthew Effect: an advantage that amplifies over time. She also identified many prior indicators of possible success of acceleration, such as mastery well above grade/age level in specific subject areas, self-directedness and independence, a dislike for repetitive work, and a preference for fast-pace learning, all pointing to a level of developmental precocity that distinguishes some students from their peers, making them well suited to an accelerated curriculum. More recently, however, the issue of whether grade-based acceleration (e.g., grade skipping) produces any learning gains compared to their non-accelerated counterparts emerged again. Using a matching procedure, Kretschmann, Vock, and Ludtke (2014) compared German students of grades 4-6 who skipped a grade and those who did not, and found no systematic advantages of grade skipping. Moreover, the authors (Kretschmann, Vock, Ludtke, & Gronostaj, 2016) found grade skipping to disadvantage girls. Indeed, researchers are probing into the complex nature of acceleration (Culross, Jolly, & Winkler, 2013).

Early college entrance is a commonly implemented form of acceleration for advanced adolescent learners (Dai, 2015). Much research has found that early college entrants enjoyed great academic successes (Brody, Assouline, & Stanley, 1990; Brody & Stanley, 1991; Janos,

Robinson, & Lunneborg, 1989; Muratori, Colangelo, & Assouline, 2003; Noble & Robinson, 1993; Olszewski-Kubilius, 1995; Sayler, 1994). Meanwhile, research also shows that some early college entrants "underachieved" (Janos, Sanfilippo, & Robinson, 1986), and they had to cope with unsatisfying grades (Gregory & Stevens-Long, 1986). There also have been incidences of academic probation (Muratori, et al., 2003). Dai, Steenbergen-Hu, and Zhou (2015) studied a cohort of early entrants in a STEM program and found diverse patterns of coping among the early entrants, some well-adjusted to the new setting, and others struggling, raising the question of what endogenous and exogenous factors are responsible for the success and failure of early college entrance.

There are several weaknesses in the way academic acceleration has been studied in general. First, the past research tended to focus overall "effects" of various forms of acceleration, with little attention paid to what exactly transpired when accelerated students took on specific curricular challenges and dealt with issues they wouldn't encountered if they were not accelerated. In other words, most research focused on some "outcome" measures (e.g., Kretschmann et al., 2014, 2016), rather than "processes", with the assumption that somehow academic acceleration (e.g., grade skipping) can automatically lead to additional learning gains other beneficial outcomes. In a recent study, McClarty (2015) found that post-acceleration opportunities (e.g., AP courses and high-ability instructional groups) have significantly enhanced accelerated learning experiences. In other words, acceleration does not mean merely faster pace; it also means depth, breadth, and complexity commensurate with the learner's level of mastery (Benbow, 1991). When learning gains are concerned, the quality of post-acceleration provisions as well as instructional support matters.

Second, related to the first weakness, the previous research tended to look at the ratio of positive and negative incidences of acceleration, particularly with respect of social and emotional adjustments (e.g., see Kulik, 2004; Robinson, 2004 for reviews); less attention was given to individual characteristics that make some accelerated students better adapt to "bigger ponds" (presumably in more challenging academic environments, with more competitive peers), and others more prone to academic and social-emotional setbacks; Roger (2004) pointed out the importance of recognizing the prior indicators of possible success of academic acceleration.

Therefore, understanding personal characteristics amenable to acceleration can facilitate better decision making regarding accelerating specific students. Moreover, the past research, by focusing on the "program" effects, did not put acceleration in the larger context of individual development in terms of the learner's history and long-term trajectories. It can be argued that only by placing acceleration in the context of long-term individual development can we fully understand its developmental consequences (Cronbach, 1996).

In view of the above research findings and limitations, this study used purposeful sampling to investigate long-term patterns of educational experiences of a distinguished group of early college entrants who studied at a prestigious STEM program in China (Special Class for the Gifted Young or SCGY, see Dai, Steenbergen-Hu, 2015 for a comprehensive description of the SCGY program), later completed doctoral programs in the United States, and went ahead to become professors at top research universities in the United States. Such purposeful sampling is intended to address three key research questions.

The first research question is: What are some identifiable endogenous factors among this group of scholars that facilitated the success of their accelerated learning and development? Bronfenbrenner (1989) identified personal characteristics that are *developmentally instigative*. For example, some characteristics such as manifested precocity and outstanding performance can be *evocative* in the sense that it tends to trigger responses from the environment, leading to new educational opportunities, which is the very phenomenon that prompted Julius Stanley to launch the SMPY study at Johns Hopkins University (Stanley, 1996). Other characteristics such as autonomous learning or autodidactic characteristics are developmentally instigative in the sense that they prompt the person to proactively seek out certain environments (e.g., books, friends) and further learning experiences. There is a host of developmentally instigative personal characteristics. Of particularly interest for this study are distinct personal characteristics revealed by this distinguished group of scientists before, during, and after their early college programs.

The second research question concerns what kinds of exogenous factors (e.g., opportunities, resources, support) they experienced from childhood to adulthood that proved significant. The developmental literature distinguishes between two conditions: typical and optimal (Fischer & Pipp, 1984; Vygotsky, 1978). The very practice of academic acceleration

represents an effort to optimize some individuals' learning environments by providing challenges and opportunities commensurate with their levels of learning abilities and their levels of cognitive and social development. Particularly related to talent development, the importance of resources and social support from family for advanced learning and interest development is well documented (e.g., Bloom, 1985; Csikszentmihalyi, Rathunde, & Whalen, 1993). Moon and Reis (2004) pointed out that "support systems" in school are needed to ensure the success of acceleration. Thus, the second research question is intended to identify exogenous factors important for the long-term success of academic acceleration through the lens of lived experiences of these ten distinguished individuals.

The third research question is about the long-term impact of accelerated learning and development. Given that an accelerated scientific research career is always decades in the making, we were particularly interested in developmental changes, transitions, milestone events, and for that matter, the timing of these developmental processes and changes, as evidenced in the lives of these ten individuals. Since successful scientific research careers are themselves low probability events (i.e., with a very low base rate), the timing of the onset of formal and informal learning and training along a line of serious learning and development becomes a crucial issue (Simonton, 1999). If academic acceleration is truly optimal for these individuals, there needs to be evidence of advantages of such an educational accommodation (or differentiation) compared to the regular age-graded schooling in terms of long-term outcomes such as early creative contributions.

In sum, this study focused on a targeted sample of established research scientists whose lived experiences of academic acceleration at various junctures of their development may shed light on the important role of personal characteristics, environmental opportunities and support, as well as milestone events they had in their developing years that helped shape their distinct trajectories of and pathways to becoming well-established or aspiring eminent scientists and professors at top research universities.

Methods

The retrospective design used in this study makes it possible to trace the developmental experiences and trajectories of these successful individuals, and understand their developmental environments, important milestone events as well as personal characteristics that jointly shape their successful accelerated research career from their childhood to adulthood (Bloom, 1985; Sosniak, 2006). More specifically, a combination of phenomenological and case methods is used to maximally capture relevant information.

Multiple sources of evidence were employed for data triangulation (Yin, 2014) in the current study. Retrospective interview were used as a main method to gain insights into what this selected group of scholars and scientists went through in the early college entrance program as well as before and after the program. Interview data represent rich accounts of lived experiences that form the basic source of reality from a *phenomenological perspective*, which emphasizes first-hand accounts of lived experience as essential for understanding a phenomenon. In addition, more intensive *biographical case investigation* was conducted based on available sources (news reports, media interviews, and books) by gathering more detailed, contextualized information about their personal backgrounds and histories. The rationale for building biographical case studies beyond the phenomenological approach was to tap into the richness and complexity of contextual events that helped shape a personal trajectory (Creswell, 1998).

An interview protocol was developed for the study. Part of it was adapted from Hertzog (2003). It consists of 22 questions, covering the following five dimensions regarding the experiences of the early college entrance program: (a) Overall experience; (b) Selection/placement; (c) Curriculum/ instruction; (d) Social/emotional; and (e) Retrospective insights. In addition, a set of questions regarding educational experiences *prior to* and *after* the college program were introduced to elicit information about (a) preschool years, (b) family and parenting, (c) elementary and secondary school years, (d) educational and general cultural experiences in the United States, and (e) retrospective insights regarding what led them to STEM academic careers.

Data Sources and Analyses

For the purpose of this study, eligible participants were defined as anyone who graduated from the SCGY, an early college entrance program at the University of Science and Technology

of China (USTC), received Ph.D. in STEM fields, and was working at an academic or research institution in the United States at the time of recruitment for this study. We contacted about 50 eligible individuals based on a list of over 80 SCGY alumni who were working at research institutions in the United States as of 2008, which is available on the SCGY website. A total of 13 individuals, 9 male and 4 female, accepted our invitation and participated in this study. The participants all came to the United States upon college graduation for pursuing doctoral degrees, and had all become faculty members of major research universities in the United States at the time of recruitment. Ten participants (7 male and 3 female) were early entrants, and three were not early entrants but honors students (dubbed "Class 00") who entered the university at the regular age of 18 but lived and studied together with early entrants. For the purpose of the present study, we focus on the 10 early college entrants. Their ages when interviewed ranged from 31 to 50, with a mean age of 41. The ages when they entered the SCGY ranged from 12 to 15, with a mean of 14 years. All of them worked at prestigious research universities at the time of interview (including Harvard, Northwestern, Purdue, Stony Brook, Univ. of Chicago, UC-San Diego, and Yale). Currently, eight are full professors and two are associate professors. Their disciplines or professions are biostatistics (n = 1), computer science (n = 3), engineering (n = 2), chemistry (n = 1), medicine (n = 1), management (n = 1), and physics (n = 1). Seven of them received National Science Foundation (NSF) Career Awards, three are fellows of their respective professions, among other honors and awards.

We followed a three-step approach in our data collection: we conducted the first round of interviews through regular or skype phone call during 2010-2012. The length of the interviews ranged from 45 to 70 minutes, with an average of 53 minutes. During 2012 to 2013, we collected supplemental documents (books and media reports) and biographical information about the interviewees to gather more data sources. Finally, through a selective sampling, we invited five representative participants (out of the ten) for a follow-up phone or skype interview in spring 2014 to revisit some of important issues emerging from the analysis of data from the first-round interview. The durations of interviews ranged from 30 to 40 minutes.

We took three steps to organize and analyze the data: (1) We conducted free note coding; a total of 116 free notes was generated and entered on NVivo, 45 of which were defined as

significant (i.e., a code more than 1/3 total participants mentioned). (2) Based on the 45 significant codes and supplemental documents, we conducted thematic analysis which delineating the common factors, endogenous and exogenous, that were identified by the interviewees as developmental important for them. And finally (3) we conducted an in-depth case study of five representative cases (persons) to create more detailed, nuanced understanding of when and how accelerated trajectories and pathways were shaped.

Results and Findings

The results and findings were organized in two parts. In Part I, we present observations that delineate a convergent academic career trajectory at the group level; Part II offers a more refined account of the talent developmental trajectory of five representative individuals from the sample using the multiple cases studies approach.

Part I. The Interplay of Endogenous and Exogenous Forces: A Phenomenological Study

We drew two concepts from the developmental literature to guide our data interpretation and thematic analysis. One is endogenous factors that are *developmentally instigative*. Personal characteristics are developmentally instigative if they are either experience-producing or experience-organizing (Dai & Renzulli, 2008), which lead to positive developmental changes in competence or character. They can be either evocative or active in nature. The other concept is exogenous factors that are *developmentally optimal*. Developmentally optimal conditions have two aspects. The first concerns the right kind of *environmental press* that prompts the individual to respond to, and act upon, the impinging opportunities and challenges to achieve their aspirations and goals. The second concerns the kind of *sociocultural support* necessary for the individual's growth and thriving. An accelerated condition is optimal when both environmental press and sociocultural support are present (Dai, 2017). Central to the present study is the following question: in what way do personal characteristics become developmentally instigative in terms of accelerating one's development, and in what way do exogenous factors provide optimal conditions in terms of facilitating such an accelerated developmental trajectory?

Developmentally instigative endogenous factors

For endogenous factors, we identified the following personal characteristics that are developmentally instigative (Bronfenbrenner, 1989): precocity, autonomous learner,

perseverance, and personal initiative. They can be seen as a cluster of traits particularly conducive to success of accelerated learning.

Precocity. In the current study, precocity refers to the exceptionally early development of mental skills compared with age peers. Most of the interviewees reported early manifestation of intellectual aptitude ahead of normal developmental schedules, as evidenced by their early literacy, early onset of formal education, multiple acceleration experiences (likely evocative in nature), and early college entrance. For example, due to the maternal health issue, the three-year old Participant #2 (female) was accidentally babysat in a kindergarten classroom in her grandmother's town where no Pre-K class was available, but she was able to capitalize on this learning opportunity and make it to the 1st grade when she was only 4. She recalled, "I refused to repeat kindergarten because I felt like I was detained, but I had learned all Pre-K materials so I insisted on attending 1st grade." Participant #3(male) recalled that his passion in math began from his childhood. He stated, "I found a book about college algebra when I was a 2nd grader. I could not comprehend the content but was fascinated by the function and formula, which might be the starting point (for my career)." In a news report, his math teacher stated that he was amazed by this student's exceptional math capability; this youngest pupil in his class never took note but was able to solve a geometry problem with 11 solutions, whereas a savvy Math teacher could not fully illustrates the 11 solutions without notes.

The autonomous learner. The second personal characteristic that was repeatedly found among this group was being autonomous or self-directed in learning; simply put, they tended to manage their own learning without external pushes or contingencies. Most of the participants reported that they self-taught themselves extra materials in advance, indicating the active nature of this distinct developmentally instigative characteristic. Participant#7 (female) stated that "I do have the habit of self-study. I believe most of my classmates did the same so that we could be ahead of class instruction." Participant #3 (male) echoed that "Since middle school, I had been spending most of time self-studying the college curriculum; classroom instruction is only part of our learning activity." Participant #6 (male) stated that, "We were highly motivated kids, while most of college students were dealing with current coursework passively, the SCGYers were

already thinking about self-teaching themselves during the summer break the courses in the upcoming fall semester courses."

Perseverance (or Grit). The third emerging theme of the personal characteristics is perseverance or grit. Duckworth, Peterson, Matthews, and Kelly (2007) defined grit as the perseverance and passion for long-term goals, and it was the strength of mind that sustains one's effort and interest toward the goal over years in spite of setbacks and adversity. Participant #2 (female) credited a lot of her career success to her focus and perseverance. She stated that "What distinguishes academia from other careers is the necessity of grit and perseverance, because there is too much frustration over the course of development, even in graduate school there were many setbacks. Those who were able to stay in academic paths might not be the most intelligent people, but they are definitely a bunch of the most persistent." In a similar way, Participant #8 (male) recalled "Once I make a certain decision, I will persistently follow through; whatever happened in the outside world has little influence on me."

Personal initiative. Personal initiative is the fourth personal characteristic identified in the data analysis. Personal initiative refers to a tendency to actively choose and pursue personal goals, rather than passively taking on goals assigned or arranged by adults (e.g., teachers or parents). Participant #8 (male) recalled that he was involved in lab research in the 2nd year of college: "My middle school (in rural area) prepared me well for the college curriculum and examination, but compared with students (with non-rural backgrounds), I did feel I was falling short of hands-on research experience. So I opted to participate in lab research very early on." In an interview, Participant#3 (male) expressed how he made his career choice: "In my sophomore year, I realized I would go to the academia." He further stated he started to conduct independent research even in graduate school years: "I got grants from private research foundations rather than from the university, so I was pretty much on my own."

Developmentally optimal exogenous factors

For exogenous factors, we look for environmental factors that are developmentally optimal, such as good timing of certain exposures and experiences, and timely technical and social support. We distinguish between two types of environmental factors that combine to make developmentally optimal conditions: one type of exogenous factors provides challenges,

opportunities, and stimulations (i.e., affordances) that evoke internal desires and drives; the other type provides the necessary support, technical or social, that helps the person more effectively deal with demands and challenges involved (i.e., goal-related constraints) in achieving desired goals. In the following section we listed evidence showing how exogenous factors (family, institution, mentors, etc.) facilitated optimal talent development in terms of supporting advanced learning and sustain a scientific research career.

Home environment and parenting conducive to children's optimal development. Data analysis revealed the existence of favorable family influences, which primarily occurred in the childhood, congruent with the emergence of child's intellectual precocity before formal education. Parents scaffolded the early onset of learning through direct literacy/numeracy teaching or early school enrollment, as well as provided informal learning such as exposing the child to a variety of explorative activities. Participant#1 (female) recalled that her father had been heavily involved in her early education: "My father believed that human can learn at a very young age, so he taught me number when I was 2 year old. He tutored me on high school curriculums three years ahead of regular schedule, so that I could use the spared time to take advantage of further academic opportunity. He transferred me to a different school multiple times to find programs that can accommodate my learning needs." In a similar way, Participant#2 (female) also recalled that her mother taught her vocabulary very early on, so academically she adjusted well in 1st grade at the age of 4. In addition, she also recalled how intellectually enriching her home environment was, how it facilitated her intrinsic motivation: "We had a big collection of books at home, and everyone in the family loved to read. Reading was naturally interesting and intrinsically enjoyable to me as a child." Participant#3 (male) also mentioned his childhood lab experience, "when I was little, my father would take me to do experiment in his lab, just for fun and it piqued my interest."

The interviewees also noted positive parenting practices that encouraged the development of endogenous qualities mentioned earlier, such as self-direction, independent decision-making, as well as the habit of self-regulation. In terms of the parents-child interactions, all the 10 participants described their parents as open-minded, warm and supportive, never demanding obedience and putting pressure on them. Participant#5 (male) thinks highly of his family

experience: “My parents had great attitude with kids, they offered as much support as they can, but they were also very hands-off so that I never felt being pushed to achieve anything in return, I am not sure if I can do a better job than they did.” By the same token, Participant#9 (male) reported a harmonious parents-child relationship simply because his parents provided “encouragement instead of pressure.” Other participants mentioned the importance of cultivating a positive mindset and nurturing good habits. Participant#2 (female) stressed the pivotal role of family influence in her life and career, “Self-discipline is a family gift of lifelong benefit. My mother made a strong effort in cultivating the habit of self-regulation before schooling, so that I was able to plan my schedule and activities, to direct myself in new environments.” Likewise, Participant#8 (male) highlighted the importance of family value, “I am independent and make most of decisions by myself, because my parents always encouraged me to keep making progress It’s okay to be in the 2nd place, but you need to reflect on what you can work on to improve.”

Institutional cultivation of STEM research competence Most of our participants reported positive early college experiences that fortified their career competence, the strengths of the SCGY program could be summarized as (a) highly challenging yet beneficial STEM curriculum, (b) flexible program setup, and (c) the technical resources and social networks that support advanced learning and oversea study.

Regarding the curriculum, the interviewees expressed a convergent impression that it was highly challenging yet beneficial in a long run. Participant#12 (male) expressed his appreciation of the SCGY foundational curriculums for its broad coverage: “there were a variety of math and physics topics to challenge your mind”. Although the curriculum was “tough,” the majority of participants recalled themselves adapting well to the challenges. Eight participants pointed out that the curriculum had prepared them well for their academic career. Participant#11 (male) stated “it equipped us with a comprehensive skillset and laid a strong foundation for my research agenda*”*. Participant#2 (female) shared the sentiment: *“*the Mathematical Analysis course equipped me with the logic in tackling abstract problems, which is essential in theoretical computation.*”* Participant#8 (male) added that the training afforded high adaptability in his career choice, *“*The rigorous curriculum enables a high starting point and a smooth transition when switching from one direction to another, both in the academic or industrial field.”

The interviewees also credited the flexibility of program setup in supporting student's interest exploration and differential learning needs. SCGY students went through two years of foundational science curriculum before formally declaring a STEM major as their specialization (see Dai & Steenbergen-Hu, 2015 for details). While most of Chinese higher education institutes do not offer students the privilege to switch majors, the unique SCGY program setup provided adequate content exposure for students to explore their strengths and interests, as well as encouraged students to make independent decisions. Participant#2 (female) recalled that "the college gave us the privilege to choose different majors and courses, and we have more degree of freedom to pick what we want." The program flexibility was also reflected in the accommodations to students' unique learning needs and paces. For example, Participant # 6 (male) mentioned that many students would study a course by themselves during school break and asked for course waiver. He stated "If you passed the waiver test in the beginning of a semester, you could take higher-level courses or do research. I waived many courses, which allowed me to work on my own research in my junior year". Participant#1(female) also recalled that the college gave her permission to graduate in 4 years and went ahead to study overseas, although the SCGY at the time was still a five-year program.

The third institutional strength, mentioned frequently during interview, was a diverse range of technical facilities, resources, and social networks for advanced learning. For example, one participant who attended SCGY in early 1980s specifically mentioned that SCGY hired native English instructors to ensure their English proficiency; as a result, most SCGYers spoke good English (Participant#7, female). Meanwhile, the SCGY's institutional affiliation with the Chinese Academy of Science (CAS) made a large selection of labs and research centers available for SCGYers' authentic scientific research experience such as internship or thesis projects. Participant#5 (male) stated "We interned at the CAS research centers for a year, and some students interned with industrial companies such as IBM or Huawei." Participant#3(male) added that, "I spent a year in Prof. XX's lab working on Computational Physics projects, which produced several journal publications and directly contributed to my admission to a PhD program at Harvard." In addition, several participants admitted that they benefited from USTC's strong social network and SCGY's prestigious intellectual credentials. Both Participant#5 (male)

and Participant#9 (male) mentioned that "the university has rich information and strong network for studying abroad, which to a large extent determined my later educational path." "Many students went abroad through the CUSPEA (China-U.S. Physics Examination and Application) program." Participant#2 (female) stated that "because our previous alumni have built up the reputations, we have had unique advantages when applying for graduate programs."

Peer stimulation and reinforcement for optimal personal growth. Ample previous research has documented the salient effect of peer environments in individual's educational aspirations and career ambitions (e.g., Roger, 2007). Through communication of ambitions, exchange of information, mutual intellectual stimulation (Astin, 1993), the SCGY peer grouping helped shape the self-belief about one's future possibilities, and reinforce the ambitious goals, aspirations, and leadership. Participant#6 (male) stated that, "Under the atmosphere of many eminent alumnus, you were inspired and pressured to do something ambitious; it urged you to work harder." Participant#10 (male) continued that "Being in such a selective group gave you certain confidence and self-esteem, if you managed to survive in this competitive environment, this confidence will stay with you". Similarly, Participant#9 (male) indicated that he became a more competitive person with the intellectual inspirations from outstanding peers. Adding to that, Participant#8 (male) stated that, "Surrounded by many excellent minds, I aspired to be the best and look forward with ambition." Overall, the results indicate an academically oriented and highly competitive peer culture is conducive to personal growth: the SCGY identity served as stimulation and motivation for the SCGYers to strive for academic and personal excellence.

Mentorships that crystallize the scholar and researcher identity. Mentors' influence is more likely to center on the transitioning and crystallizing phases of talent development (Dai, 2017). In her seminal paper, Zuckermen (1992) concluded that the role of mentorship can be divided into two facets-- cognitive inculcation and cultural socialization. Cognitive inculcation refers to modeling the standard of performance, the style of work, the knowledge, skills and behavior patterns to approach or solve a problem. For example, Participant#3 (male) acknowledged that "My mentor Randy manages to get most physics out of as little calculation as possible, which has a lot of influence on my own style of research." Participant#9 (male) recalled that "Working with my PhD advisor helped me develop high standards in my own work. Being

associated with him also made it easy for me to build my own connections and academic career." One the other aspect, mentor's cultural socialization effects includes reinforcing the value, attitude, self-image and expectation of a professional identity, serving as the role model of committed scholar and devoted researcher. Reflecting on this point, Participant#13(female) stated that "My Ph.D. advisor guided me through multiple challenges from work to life domains. Her mentorship made a very positive impact on me and motivation me to become an academic". Participant#2(female) echoed that "Prof. Chen from the Department of Computer Science is someone I highly respected and admired. She was a great scholar, devoted teacher, but is also socially savvy. She was a great role model".

The Interplay of Endogenous and Exogenous Forces

To further illustrate the interplay of endogenous and exogenous forces in the course, we constructed a thematic map to provide a process account for the convergent STEM research career phenomenon (see Figure 1). The thematic map specifies four phases in the boxes (pre-, during, and post-SCGY, and academic research career). For each phase, major endogenous personal factors are presented in the box, and exogenous (formal and informal educational and social) factors in each phase are identified above and below the box. Continuities and changes of these personal and environmental factors can be seen across phases to indicate developmental transitions and milestone events, which conceptually highlighted how the dynamic interplay between endogenous and exogenous forces (home environments and school/college experiences) jointly shapes and sustains an accelerated talent development, subsequently leading to a scientific research career.

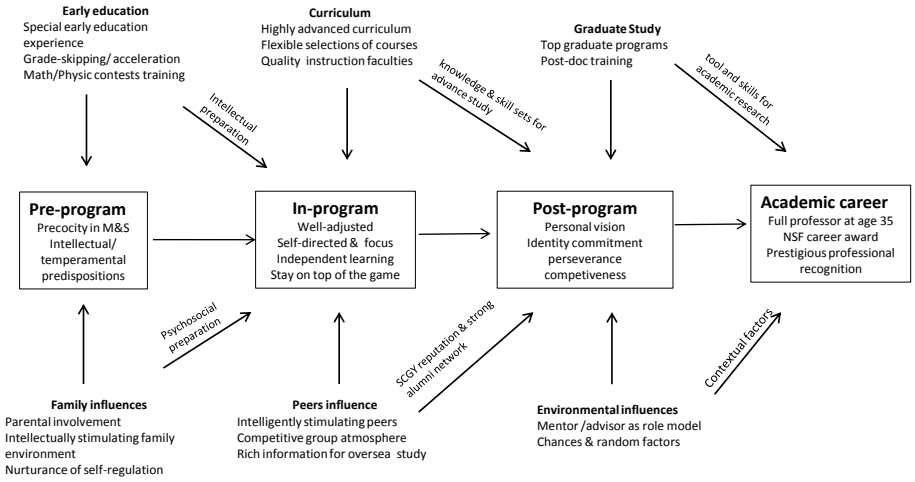

Figure 1: Thematic map of early entrants' academic trajectory

Figure 1. A thematic map of early entrants' academic trajectory

Part II. The Long-Term Developmental Trajectories: Multiple Case Studies

To provide person-level accounts of the accelerated scientific research career, we conducted a multiple-case study of five representative participants out of the ten interviewees. It allowed for an up-close, in-depth exploration of the multiple cognitive, affective and environmental factors in the shaping of their academic career. The following is a brief profile of each individual (all names used are pseudo names):

> **Profile of Tina**: Began her formal education at age 4, completed her elementary schools at 9 and entered SCGY at 14, graduated at 18 and received her Ph.D. at Harvard at 22, recognized as a Fellow of American Statistical Association and currently a full professor at Harvard University. Her profile includes precocity, father's active involvement in her early education and acceleration. Tina's father has unique educational philosophy highlighting the role of "early head-start, determination, and self-regulated learning." As a result, all of Tina's five brothers completed graduate degrees, and two of them received

Ph.D. from top US universities. The milestone event for Tina's academic career was a pharmaceutical internship, which made her realize that working with a company was not her favorable option, as she enjoyed the freedom to explore and pursue her own intellectual interests.

Profile of Simmons: Attended a radically accelerated secondary program for gifted children at the age of eight, entered SCGY at age 12.5, graduated at 18, pursued his Ph.D. in Physics at Harvard, became an assistant professor at Harvard at the age of 25 and received the NSF career award at 26. His profile includes very high mathematical interest and precocity (reading a calculus book in 2nd grade), self-direction and the highly focused pursuit of interests. He highlighted his radically accelerated experiences in secondary school as pivotal, providing him with the most balanced and efficient education experiences, while SCGY was just a natural option of college acceleration. Simmons's aspiration to be an academic was crystalized when he was a college sophomore.

Profile of Jessica: Attended elementary school at the age of 4, entered SCGY at age 12, pursued Ph.D. in Computer Science at Stanford the age of 18, after a one-year post-doc at California Institute of Technology, started an academic career at Stony Brook University and received the NSF career award at age 24. Her profile includes precocity, intellectually stimulating home environment, and high maternal involvement in early literacy and nurturing the habit of self-regulation. Milestone events include teachers and mentors who motivated her to pursue an academic career.

Profile of Jimmy: Attended elementary school at the age of 5, entered SCGY at age 14, started a Ph.D. program in Chemistry at Stanford at the age of 19. After three-year post-doc training in Scripps Research Institute, he became an assistant professor at Boston College and received the Smith Family Young Investigator Award at age 27. His profile includes high parental expectation, high independence and competitiveness in personality, a combination of interest and talent as a basis for an academic career.

Profile of Don: Skipped the 5th 6th grade and went to a special preparation school at age10 and finished the SCGY program at 19. After graduate work in Singapore, he entered the Ph.D. program in Electric Engineering at Princeton at the age of 23, became an assistant professor at Northwest University at 28, and received a NSF Early Career Award at age 31. His profile includes accelerated early education and distinct personality characteristics leading to an academic career (e.g., preferring intellectual independence and flexibility to monetary gains). His milestone events include SCGY experience (curriculum) as life-changing, and mentorship at Princeton. He also mentioned the chance factor in shaping his academic career.

While similarities of the five cases can be observed, including similar patterns of precocity and developmental trajectories, uniqueness of developmental conditions and life circumstances can also be detected. It seems that environmental factors and events shaped these individuals' life paths in varying degrees. For example, for Simmons, the developmental trajectory seems highly robust regardless of environmental circumstances. For Tina, environmental conditions and opportunities played a more critical role in shaping her life path every step of the way. The five case analyses suggest a continuity of the dynamic interplay of endogenous and exogenous forces, from endogenous dominance (robustness of ontogeny) to exogenous dominance (adaptability of ontogeny). Despite the developmental variability within this small sample, the accelerated trajectories of their academic and research careers led to fruition in a similar way. Figure 2 plots the developmental trajectories of the five individuals and compares them with a more common trajectory of a aspiring research scientist (the bold dash line), which is based on the data drawn from the 2003 report on doctorate recipients in the US conducted by the National Science Foundation and other five institutions (Hoffer et al., 2004).

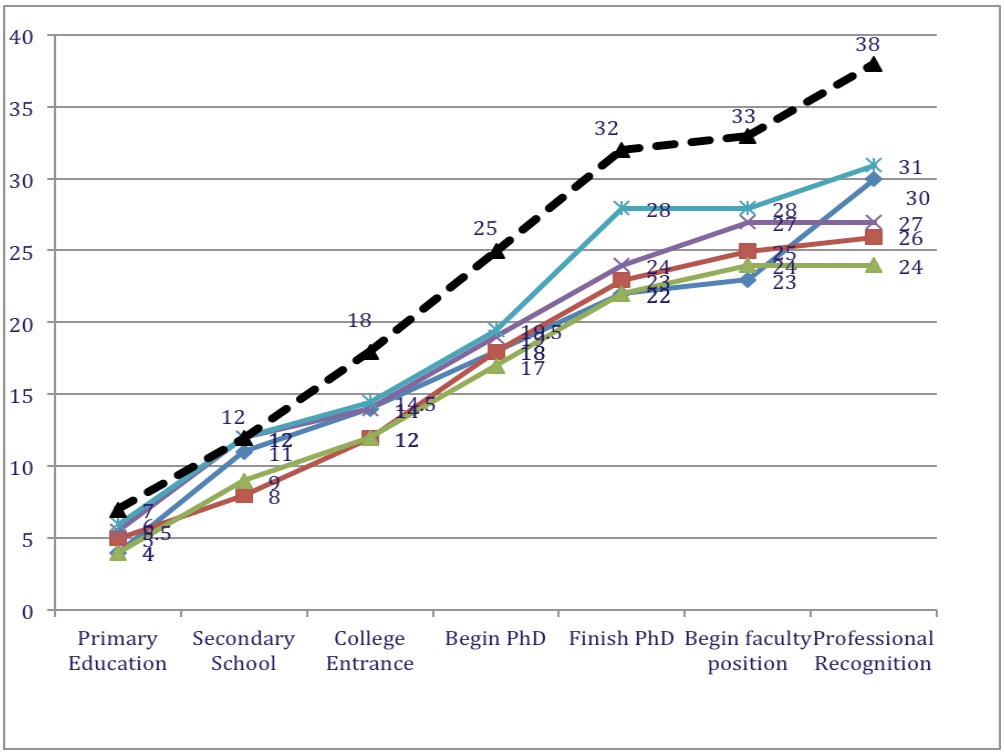

Figure 2. Milestone events by age --- trajectories of five SCGY graduates from preschool years to professional recognition

Note. Typical person data from NSF 2003 doctorate recipients in US report (Hoffer, 2004).

As illustrated in Figure 2, compared to a typical developmental timeline of an academic scholar (i.e., attending college at 18, finishing Ph.D. at 32 and getting tenure at age 38), these five individuals attended college (Mean age = 14), completed doctoral programs (Mean age =23.8) and received tenure (M=27.6) at much young ages. When we use professional recognition (e.g. NSF career award, prestigious organizational fellowship) as an early hallmark of creative contributions. Early college entrance by an average of three years ahead of regular college goers (at the age of 18) was translated into professional recognition roughly ten years ahead of regulars, which signifies a career trajectory truly "accelerated" in the exact sense of the word.

The five interviewees provided some hindsight regarding advantages of having an early head-start, or a developmental leverage. As Tina stated, "When you start the training early, it

gave you a good use of time. At the age of innocence, you were more engaged in learning with a single-minded determination. If you enter college at the normal age, there are lots of distractions. I was protected from the anxiety over 'rushing and running out of time'." The others also related to the fact that while in teens or early 20s, one has less pressure for fulfilling the social roles and family obligations (employment, marriage and child rearing) and can be more focused. There are other developmental advantages of starting early. However, the previous observations of endogenous and exogenous forces need to be taken into account to fully understand this accelerated career trajectory as we shall discuss in the next section.

Discussion

The preponderance of research indicates that various forms of academic acceleration are viable education options for precocious children. However, the question is what makes them work: what factors and mechanisms make academic acceleration truly developmentally optimal. The present study set out to answer this question by purposefully selecting 10 individuals whose scientific career has already born fruition. It is intended to construct a theoretically meaningful account of how an accelerated scientific career trajectory was taking it shape based on the lived experiences and biographic case analyses of the ten individuals.

It is fair to characterize these individuals' successful stories as carrying an element of luck or chance factor (Gagné, 2005; Tannenbaum, 1983) in terms of have the right person (endogenous) in the right place (exogenous) at the right time (the developmental timing of their encountering and interaction). There are also developmental variability within this sample in terms of who initiated an accelerated path, whether the trajectory was shaped mainly by endogenous or exogenous forces, and how it was temporally unfolded. However, their stories also convey a sense of inevitability when we consider how environmental opportunities and challenges impinged upon them, and how the resources, tools, and support unleash their potential and favor their long-term development every step of the way. As shown in Figure 1, we consider the interplay of endogenous and exogenous forces as *dynamic* because developmentally instigative characteristics (e.g., precocity or the autonomous learner) can be dormant unless stimulated and nourished by the environments; developmentally optimal conditions provide timely opportunities and at the same time enable the individuals to deal with developmental tasks

more effectively. The interplay is dynamic in another sense: At any new level of development along this accelerated trajectory, there are new kinds of challenges and opportunities that demand new endogenous qualities (e.g., perseverance) and new technical and social support (e.g., pedagogy, peer support, and mentorship). This dynamics can be seen as a Push-and-Sustain mechanism (Dai, 2017) that propels an accelerated talent development trajectory.

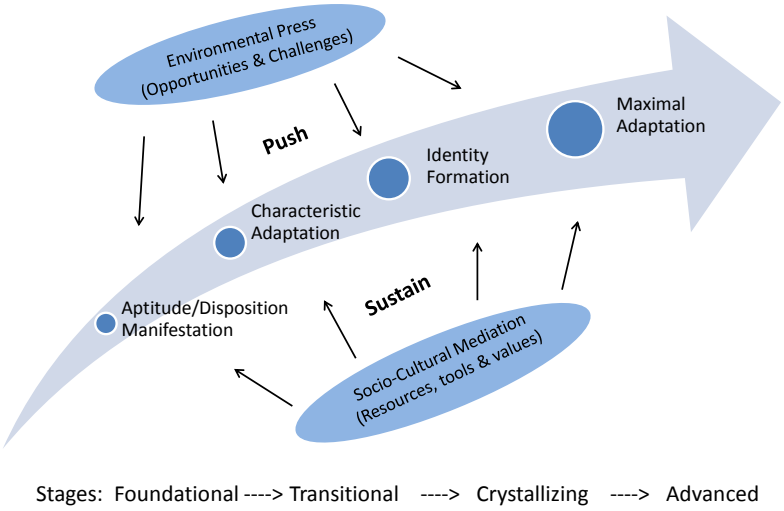

Figure 3. A schematic representation of Evolving Complexity Theory of talent development (Dai, 2017).

Note: The curved arrow represents the person (with endogenous resources) undergoing developmental changes while interacting with opportunities and challenges (environmental press); the process is mediated by social-cultural forces (exogenous factors) every step of the way. The model emphasizes the adaptive aspect of talent development in that environmental press "pushes" the person to adapt and grow, and endogenous forces (person) mediated and supported by social-cultural forces sustain the growing power. Thus, evolving complexity of talent development is fundamentally shaped by adaptive responses as well as adaptive developmental changes (e.g., characteristic and maximal adaptations).

The previous research shows that academic acceleration tends to produce additional knowledge gains (Roger, 2004). What can be gained in a long run? What are developmental underpinnings? The results of the present study provide important clues by virtue of putting academic acceleration in a larger context of a scientific career that is decades in the making. Figure 2 shows that the accelerated pace of educational progression of the ten individuals in this study truly accelerated a trajectory of becoming a well-established scientist in terms of at what age one gets tenure and professional recognition (e.g., NSF CAREER award). How do we explain this accelerated trajectory? A sensible answer is that the dynamic interplay and reciprocation of endogenous and exogenous forces discussed earlier has a multiplicative, rather than additive, effect on development (see Papierno, Ceci, Makel, & Williams, 2005). Furthermore, the right *person* in the right *place* at the right *time* may have created a combustion effect, as it were; namely, it led to qualitative (not just quantitative) changes (e.g., intensified interest, early commitment to a scientific career, and creative insight), a point highlighted by Renzulli' (1986) three-ring theory of giftedness.

In light of the evidence of the present study, there is another, more straight-forward explanation: the accelerated scientific career was due to the early onset of a scientific career made possible by the early college entrance to the SCGY program (Robinson, 2005); the ten SCGYers majoring in STEM fields gained significant amounts of professional experiences with lab research and year-long internship and mentorship program with cutting-edge researchers. An earlier study of the SCGY program (Dai, Steenbergen-Hu, & Zhou, 2015) indicates that many SCGYers experienced a critical transition from being a good student (characteristic adaptation) to being an aspiring scientist (maximal adaptation). *Characteristic adaptation* refers to a characteristic way the individual responds to, and act upon, environmental opportunities and challenges. All the interviewees in the present study can be categorized as belong to a well-adjusted group who are on top of the game in the STEM program. However, maximal adaptation means a concerted effort to master the *modus operandi* of a professional domain (e.g., initiating research projects at the intellectual as well as technical level) and measuring up to much higher standards of excellence (e.g., writing research papers). Some of the interviewees mentioned that, while still teenagers, they were doing scholarly and research work that only graduate students are

expected to do. Thus, we can attribute the accelerated scientific career to the intensity of advanced learning and professional training compared to their regular age peers who were still memorizing textbook materials and doing "school work" in high school.

Related to the early transition explanation discussed above is another possibility that academic acceleration in STEM subjects, compared to social sciences or humanities, is particularly viable for scientifically talented teenagers, because these disciplines are formal and technical in nature and do not require a lot of social experience and maturity. Jung, Young, and Gross (2015) advanced this conjecture based on their research on an early college entrance STEM program. In their view, academic acceleration may be more effective and meaningful in STEM subjects than, say social sciences. We further argue, based on the current study as well as the past research on age and achievement (Lehman, 1953), that early onset of a scientific research career is conducive creativity productivity due to a developmental advantage: for the ten individuals in the present study, enduring experience with relevant disciplines, skillsets and expertise developed, and creative energy came together at the right developmental timing (in mid-twenties) to allow them flourish professionally at a much earlier age. For that matter, quality education experiences they obtained over time in the United States as well as China, the access to cutting-edge labs and leading scientists as mentors (almost all these interviewees pursued doctoral degrees at first-tiered universities such as Harvard and Stanford), and even the prestige of SCGY, were all contributing factors.

Limitations and Practical Implications

The present study attempted to look behind an accelerated scientific career to uncover its developmental underpinnings in terms of dynamic interplay of endogenous and exogenous forces every step of the way from childhood to adulthood. The study used a qualitative approach (retrospective interview and case analysis of successful individuals who have multiple experiences of academic acceleration in their developing years), as we believe that many insights into the developmental processes and mechanisms can be achieved. The function of the qualitative research like the current one is not to test any hypotheses but generate conjectures and theoretical arguments that can be subjected to further investigation and confirmation (or disconfirmation).

This said, we also recognize that many explanations and theoretical arguments, albeit grounded in the data, are still tentative, subject to further investigation. However, we should point out quickly that the explanations we provided earlier is also informed by the preponderance of the extant research on the topic, include our previous research (Dai & Steenbergen-Hu, 2015; Dai & Steenbergen-Hu, Zhou, 2015). Evidence obtained from this study also substantiates many theoretical arguments made in an Evolving Complexity Theory of talent development (Dai, 2017). Interestingly, although the participants in the present study all grew up and completed their primary, secondary, and tertiary education (SCGY program) in China, what we found on their acceleration experiences and developmental outcomes is surprisingly similar to what is found in the Western countries (see Colangelo et. al., 2004; Steenbergen-Hu et al., 2016). For example, different from the prevalent traditional Chinese parenting that tends to exercise high psychological control (Ng, Pomerantz, & Deng, 2014) and exert pressure on academic achievement, parenting reported by the participants was consistently autonomy supportive (to use their own words, "hands-off"). It is possible that these precocious children do not need to be pushed to do well in school in the first place, but a more important reason may be that they have learned early on what they wanted, and their parents respected their choice and individuality. Practical implications of understanding what is behind the success of academic acceleration are profound, for example, when to accelerate, who is more likely to succeed, what needs to be in place in terms of resources and support to ensure success. The present study yields useful insights regarding these issues.

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