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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 the 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 USA research universities. The purpose of the study was to find out (1) what some identifiable endogenous factors were about 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 that enhanced the successful acceleration experience; and (3) how these endogenous and exogenous factors facilitated their developmental transitions every step of the way, especially from the role of a student to that of an aspiring scientist. These questions are addressed in light of evolving complexity theory. Retrospective interviews were used for data collection. Thematic analysis of the codes from interview data yielded a conceptual map. A distinct set of endogenous and exogenous factors at different developmental junctures were identified, and their dynamic interplay was delineated to account for accelerated trajectories toward a scientific research career. The theoretical significance and practical implications of the study for talent development in science are discussed.

Keywords: academic acceleration; early college entrance; talent development; career trajectories; phenomenological study

1. Introduction

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 [1–5]. Although there are many forms of academic acceleration, depending on developmental timing and practical circumstances [6], the main impetus is to provide academic challenges commensurate to the more advanced levels of competence and the faster pace of learning that some students demonstrate. Based on the early research, Feldhusen et al. [7] proposed twelve guidelines for procedures and criteria regarding decision-making on academic acceleration. Rogers [8] conducted a comprehensive review of research on subject-based and grade-based acceleration with K–12 students and concluded that many forms of academic acceleration tended to produce additional growth in knowledge and skills. She also identified many prior indicators of the possible success of acceleration, such as mastery well above the student’s grade/age level in specific subject areas, self-directedness, independence, a dislike for repetitive work, and a preference for fast-paced learning, all pointing to a level of developmental precocity that distinguishes some students from their peers, making them well-suited to an accelerated curriculum. Her recent meta-analysis of 26 forms of academic acceleration [8] further

confirmed and extended these conclusions. Feist [9] found in a study of Westinghouse Science Talent Search finalists that the early start of scientific interest and productive experiences was associated with high accomplishments in the adult years.

More recently, however, the issue emerged again as to whether grade-based acceleration produces any surplus learning gains for gifted students compared to their nonaccelerated counterparts. Using a matching procedure, Kretschmann et al. [10] compared German students in grades four to six who skipped a grade and those who did not and found no systematic advantages in grade skipping. Moreover, the authors [11] found in another study that grade skipping disadvantaged girls. Indeed, researchers are probing into the complex nature of acceleration [12]. While psychological well-being is an enduring concern for academic acceleration, a recent longitudinal study of gifted students who had been accelerated prior to high school and by the age of 25, respectively, found no evidence of related long-term problems [13], though apparent negative effects on self-concept with the more advanced academic placement inherent in acceleration were consistently found [14,15].

Early college entrance is a commonly implemented form of acceleration for advanced adolescent learners [16]. Much research has found that early college entrants enjoyed great academic success [17–23]. Meanwhile, research has also shown that some early college entrants did not do well and underachieved [19,24], and they had to cope with unsatisfying grades [25]. There also have been instances of academic probation [20]. Dai et al. [26] studied a cohort of early entrants in a STEM program and found diverse patterns of coping among the early entrants, with some well-adjusted in 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 weaknesses in the way academic acceleration has been studied in general. First, past research tended to focus on the 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 would not have encountered if they were not accelerated. In other words, most research focused on some outcome measures e.g., [10,11] rather than processes, with the unwarranted assumption that somehow academic acceleration (e.g., grade skipping) can automatically lead to additional learning gains or other beneficial outcomes. In a recent study, McClarty [27] found that postacceleration opportunities (e.g., AP courses and high-ability instructional groups) have significantly enhanced accelerated learning experiences. In other words, acceleration does not mean merely a faster pace; it also means depth, breadth, and complexity commensurate with the learner's level of mastery [28,29]. In a recent interview study of mathematically gifted and accelerated students in Norway [30], the issue was brought up by these students as to the lack of sufficient challenges as well as sufficient mathematical knowledge on the part of teachers. Where learning gains are concerned, the quality of postacceleration provisions, instructional support, and even school culture matters (see [31]).

Second, related to the first weakness, previous research tended to look at the ratio of positive and negative incidences of acceleration, particularly with respect to social and emotional adjustment e.g., see [32,33] for reviews; less attention was given to individual characteristics that made 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. Rogers [8] pointed out the importance of recognizing the prior indicators of the possible success of academic acceleration. Based on their long-term follow-up study, Hertzog and Chung [34] raised concerns about social-emotional readiness for academic acceleration in general and early college entrance programs in particular. Therefore, understanding personal characteristics amenable to acceleration can facilitate better decision-making regarding accelerating specific students. Moreover, past research, by focusing on the program effects, did not put acceleration into the larger context of talent development in terms of the learner's history and long-term trajectories [35]. It can be argued that only by placing acceleration into the context of long-term individual development can we fully understand its developmental

consequences [36]. More specifically, both endogenous and exogenous factors need to be identified as meaningful facilitators of successful accelerated learning and development.

In view of the above research findings and limitations, this study used purposeful sampling to investigate the long-term patterns of educational experiences of a distinguished group of early college entrants who studied at a prestigious STEM program in China (the Special Class for the Gifted Young, or SCGY; see [37] for a comprehensive description of the SCGY program), later completed doctoral programs in the United States, and went on to become professors at top research universities in the United States. The purposeful sampling was intended to address three key research questions.

The first research question is as follows: what are some identifiable endogenous factors among this group of scholars that facilitated the success of their accelerated learning and development? Bronfenbrenner [38] 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 they tend to trigger responses from the environment, leading to new educational opportunities, which is the very phenomenon that prompted Julius Stanley to launch the Study of Mathematically Precocious Youth (SMPY) at Johns Hopkins University [39]. 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, projects, people) and sustain further learning experiences. There is a host of developmentally instigative personal characteristics to look into. Of particular interest for this study are the 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) the participants experienced from childhood to adulthood that proved significant. The developmental literature distinguishes between two conditions: typical and optimal [40,41]. 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 ability and their levels of cognitive and social development. Particularly relevant to talent development, the importance of resources and social support from family for advanced learning and interest development is well-documented (e.g., [42,43]). Moon and Reis [44] pointed out that support systems in schools are needed to ensure the success of acceleration. Thus, the second research question was intended to identify exogenous factors important for the long-term success of academic acceleration through the lens of the lived experiences of the participants.

The third research question is how identified endogenous and exogenous factors facilitate a developmental transition every step of the way, especially from being merely good students to developing an identity as aspiring scientists. Evolving complexity theory (ECT; [45]) postulates that, for full commitment to a scientific career, one has to develop an identity as a future scientist. This identity development is a gradual process involving early exposure, positive experiences (e.g., interest and self-efficacy), mastery of the modus operandi in a domain, and viable prospects of a long-term commitment to such an undertaking at the professional level. It was therefore important to know in what way the endogenous and exogenous forces were reciprocated to create a career path to becoming research scientists.

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 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.

2. Methods

The retrospective design used in this study made it possible to trace the developmental experiences and trajectories of these successful individuals and understand their developmental environments, important milestone events, and personal characteristics that jointly shaped their successful accelerated research career from their childhood to adulthood [42,46].

2.1. Participants

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 PhD in a STEM field, and was working at an academic or research institution in the United States at the time of recruitment for this study. The SCGY is the most prestigious early college entrance program in China. The admission procedures and criteria include passing college entrance exams with good standing, an IQ score of 130 or higher, an in-person interview as a finalist, and a one-week on-campus course followed by an exam related to the learning materials covered in the course. Each year, more than two thousand applicants applied for the SCGY, and about 50 were accepted (because of the expansion of the program, the SCGY has become a school in recent years and admits more students; see [37] for more details).

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, nine males and four females, accepted our invitation and participated in this study. The participants all came to the United States upon college graduation to pursue doctoral degrees and had all become faculty members of major research universities in the United States at the time of recruitment. Ten participants (seven males and three females) were early entrants, and three were not early entrants but honors students (dubbed the “00 Class”) who entered the university at the regular age of 18 but lived and studied together with the early entrants. For the purpose of the present study, we focused on the 10 early college entrants. Their ages when interviewed ranged from 31 to 50, with a mean age of 41. Their 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 their interviews (including Harvard, Northwestern, Purdue, Stony Brook, the University 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, and three are fellows of their respective professions, among other honors and awards.

2.2. Procedures

A phenomenological approach [47] was used to maximally capture the lived experiences of the participants. Retrospective interviews were used as the main method to gain insight 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 firsthand accounts of lived experiences as essential for understanding a phenomenon [47]. Other sources of information (e.g., media reports and biographical information) were also employed for data triangulation [48] in the current study.

2.3. Interview Protocol

An interview protocol was developed for the study. Part of it was adapted from Hertzog [49]. It consisted 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 aspects, and (e) retrospective insights. In addition, a set of questions regarding educational experiences prior to and after the college program was introduced to elicit information about (a) the preschool years, (b) family and parenting, (c) the 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. Interviews were conducted through

regular phone or Skype calls. The length of the interviews ranged from 45 to 70 minutes, with an average of 53 minutes. Interviews were transcribed verbatim.

2.4. Data Compiling and Analyses

In addition to interview data, we collected supplemental documents (books and media reports) and biographical information about the interviewees for more information. We took three steps to organize and analyze the data: (1) We generated free codes; a total of 116 free codes were generated and entered into NVivo, 45 of which were defined as significant (i.e., a code that more than one-third of the total of participants mentioned). (2) Based on the 45 significant codes and supplemental documents, we conducted a thematic analysis, which delineated the common factors, endogenous and exogenous, that were identified by the interviewees as developmentally important for them. Finally, (3) we mapped out the endogenous and exogenous factors at play in different developmental phases in an effort to address the question of how the scientists' career paths developed every step of the way.

3. Findings

We drew from two concepts from the developmental literature to guide our data interpretation and thematic analysis. One concerns endogenous factors that are developmentally instigative (Bronfenbrenner, 1989). Personal characteristics are developmentally instigative if they are either experience-producing or experience-organizing [50], 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 [40]. 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 aspect concerns the kind of sociocultural support necessary for the individual's growth and thriving. According to ECT, an accelerated condition is optimal when both environmental press and sociocultural support are present [16], in press. Central to the present study is the following question: in what way do personal characteristics become developmentally instigative in terms of being highly responsive to developmental opportunities, such as accelerated learning and development, and in what way do exogenous factors provide optimal conditions in terms of facilitating such an accelerated developmental trajectory?

3.1. Endogenous Forces That Were Developmentally Instigative

For endogenous factors, the following developmentally instigative personal characteristics were identified: precocity, being an autonomous learner, perseverance, and personal initiative. They can be seen as a cluster of traits particularly conducive to the success of accelerated learning and development.

3.1.1. Precocity

In the current study, precocity refers to the exceptionally early development of mental skills compared with same-age peers. Most of the interviewees reported an early manifestation of intellectual aptitude ahead of normal developmental schedules, as evidenced by their early literacy, early start of formal education, multiple acceleration experiences (likely evocative in nature), and early college entrance. For example, due to maternal health issues, 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 made it to the first grade when she was only four. 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 first grade." Participant 3 (male) recalled that his passion for math began in his childhood. He stated, "I found a book about college algebra when I was a second 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 notes but was able to solve a geometry problem with 11 solutions, whereas a savvy math teacher could not fully illustrate the 11 solutions without notes.

3.1.2. 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. Half of the participants reported that they taught themselves extra materials in advance, indicating the proactive 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 to prepare for the upcoming courses in the fall semester."

3.1.3. Perseverance or Grit

The third emerging theme in the personal characteristics was perseverance or grit. Duckworth, Peterson, Matthews, and Kelly (2007) defined grit as perseverance and passion for long-term goals, and it is the strength of mind that sustains one's effort and interest toward the goal over the 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 on 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."

3.1.4. Personal Initiative

Personal initiative was the fourth personal characteristic identified in the data analysis. Personal initiative refers to a tendency to actively seek opportunities 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 second year of college: My middle school (in a rural area) prepared me well for the college curriculum and examination, but compared with other students (with nonrural 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 academia." He started to conduct independent research in his graduate school years: "I got grants from private research foundations rather than from the university, so I was pretty much on my own."

3.2. Exogenous Forces That Are Developmentally Optimal

For exogenous factors, we looked for environmental factors that were developmentally optimal, such as good timing of certain exposures and experiences and timely technical and social support. We distinguished between two types of environmental factors that combine to make developmentally optimal conditions: one type of exogenous factor provides challenges, opportunities, and stimulation (i.e., affordances) that evoke internal desires and drives (what is collectively called in ECT "environmental press"; see Dai, 2017); 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 the desired goals. In the following section, we list evidence showing how exogenous factors (family, institution, mentors, etc.) facilitated optimal talent development in terms of supporting advanced learning and sustaining a scientific research career.

3.2.1. High Parental Involvement in Formative Years

Data analysis revealed the existence of favorable family influences, which primarily occurred in childhood, congruent with the emergence of the child's intellectual precocity before formal education. Parents scaffolded the early start of learning through direct literacy/numeracy teaching or early school enrollment as well as providing 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 humans can learn at a very young age, so he taught me number when I was two years old. He tutored me on high school curriculums three years ahead of regular schedule so that I could use the spare 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 first grade at the age of four. In addition, she also recalled how intellectually enriching her home environment was and 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 experiments in his lab, just for fun, and it piqued my interest."

The interviewees also noted positive parenting practices that encouraged the development of the endogenous qualities mentioned earlier, such as self-direction, independent decision-making, and the habit of self-regulation. In terms of parent-child interactions, all 10 participants described their parents as open-minded, warm, and supportive, never demanding obedience or putting pressure on them. Participant 5 (male) thought highly of his family experience: "My parents had great attitudes 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 parent-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 influences 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 values: "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 second place, but you need to reflect on what you can work on to improve."

3.2.2. 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) a highly challenging yet beneficial STEM curriculum, (b) a flexible program setup, and (c) the technical resources and social networks that support advanced learning and overseas studies.

Regarding the curriculum, the interviewees expressed a convergent impression that it was highly challenging yet beneficial in the long run. Participant 12 (male) expressed his appreciation of the SCGY foundational curriculum 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 skill set 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 him 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 the program setup with supporting students’ interests, explorations, and differential learning needs. SCGY students went through two years of the foundational science curriculum before formally declaring a STEM major as their specialization (see [37] for details). While most Chinese higher education institutes do not offer students the privilege of switching majors, the unique SCGY program setup provided adequate content exposure for students to explore their strengths and interests as well as encouraging students to make independent decisions. Participant 2 (female) recalled that, “the college gave us the privilege to choose different majors and courses, and we had more degrees of freedom to pick what we want.” The program flexibility was also reflected in the accommodations of students’ unique learning needs and paces. For example, Participant 6 (male) mentioned that many students would study a course by themselves during the school break and later get a 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 four years and go on to study overseas although the SCGY at the time was still a five-year program.

The third institutional strength, mentioned frequently during interviews, was a diverse range of technical facilities, resources, and social networks for advanced learning. For example, one participant who attended the SCGY in the early 1980s specifically mentioned that the SCGY hired native English-speaking 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 Sciences (CAS) made a large selection of labs and research centers available for SCGYers’ authentic scientific research experiences, such as internships 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 Professor 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 the 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 their reputations, we have had unique advantages when applying for graduate programs.”

3.2.3. Peer Stimulation and Reinforcement for Optimal Personal Growth

Ample previous research has documented the salient effect of peer environments on individuals’ educational aspirations and career ambitions (e.g., [51]). Through the communication of ambitions, exchange of information, and mutual intellectual stimulation [52], the SCGY peer group helped shape the self-belief about one’s future possibilities and reinforce 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 inspiration 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 indicated that an academically oriented and highly competitive peer culture was conducive to personal growth: the SCGY identity served as stimulation and motivation for the SCGYers to strive for academic and personal excellence.

3.2.4. Mentorships that Crystallize the Scholar and Researcher Identity

Mentors’ influence is more likely to center on the transitioning and crystallizing phases of talent development [45]. In her seminal paper, Zuckerman [53] 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, style of work, 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 of the other aspects, the mentor’s cultural socialization effects include reinforcing the value, attitude, self-image, and expectation of a professional identity, serving as the role model of a committed scholar and devoted researcher. Reflecting on this point, Participant 13 (female) stated that, “My PhD advisor guided me through multiple challenges from work to life domains. Her mentorship made a very positive impact on me and motivated me to become an academic.” Participant 2 (female) echoed that, “Professor 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.”

3.3. Dynamic Interplay of Endogenous and Exogenous Forces

To further illustrate the interplay of endogenous and exogenous forces over the course of individual development, we constructed a thematic map to provide a process accounting 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 in these personal and environmental factors can be seen across phases to indicate developmental transitions and milestone events, which conceptually highlights how the dynamic interplay between endogenous and exogenous forces (home environments and school/college experiences) jointly shaped and sustained an accelerant’s talent development, subsequently leading to a scientific research career.

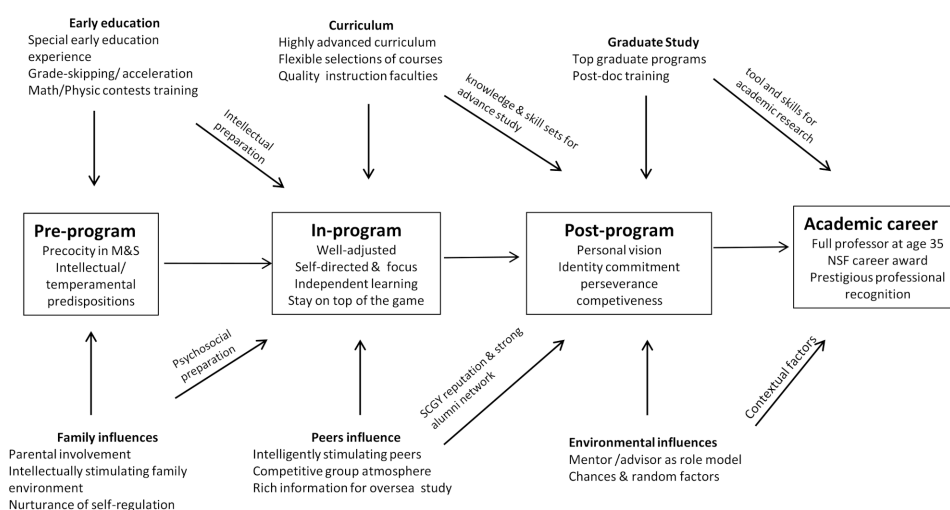


Figure 1. A thematic map of early entrants’ long-term academic trajectory toward a scientific research career.

Based on this integration of endogenous and exogenous factors in explaining an accelerated scientific career trajectory, we made the following observations regarding the dynamic interplay of endogenous and exogenous forces prior to, during, and after the early college entrance program.

3.3.1. Prior to the Program

Although precocity was demonstrated early for these individuals, the process of becoming autonomous learners was nonetheless facilitated by their parents. Most noticeable was a pattern of parenting that was characterized by nurturing the love of learning and self-direction early on and then having a hands-off policy once the child became more capable of taking self-initiative and navigating learning on their own. This practice becomes more illuminating when Chinese parents tend to exert much behavioral and psychological control over their children even throughout their childhood [53,54]. Of course, there could also be a child's effect on parenting in that autonomous learners rendered parental control unnecessary. Overall, compared to early college entrants [26], this group of individuals showed better preparation for early college entrance.

3.3.2. During the Program

This group of early college entrants were among the most successful ones among their cohorts. From a cohort of the same college entrance program, Dai et al. [26] identified four patterns of characteristic adaptation: (a) being well-adjusted, (b) having an uphill battle, (c) playing by one's own rules, and (d) drifting apart. In comparison, individuals in this study were all well-adjusted. The challenging curriculum, the program flexibility, and the resources available to them motivated rather than overwhelmed them. Clearly, they seized the opportunity and made the most of it. Not least is the fact that this group of individuals saw their peers as an asset, a source of intellectual stimulation, rather than a threat to their self-esteem, as in the case of the big-fish–little-pond effect that is quite prevalent in the program [26].

3.3.3. After the Program

Most of the individuals in this study started to pursue their PhD programs at around 18 years of age. Also noticeable was the fact that the programs they attended were among the best in the United States. Amid this backdrop, it is quite revealing that almost all interviewees in this study highlighted the role of the mentorship they experienced during their doctoral programs in making them firmly committed to a scientific career. Several of them did a postdoc before landing an academic job. One tried a more lucrative job with a company but eventually joined a university faculty due to a preference for intellectual autonomy in research. Not surprisingly, most of them became full professors in their thirties, professionally well-established as scientists.

4. Discussion

A preponderance of research indicates that various forms of academic acceleration are viable educational options for precocious children [6]. 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 careers have already borne fruit. It was intended to construct a theoretically meaningful account of how an accelerated scientific career trajectory was taking shape based on the lived experiences of the ten individuals.

4.1. Thematic Interpretation in Light of ECT

It is fair to characterize these individuals' success stories as carrying an element of luck or chance [55,56] in terms of having the right person (endogenous) in the right place (exogenous) at the right time (the developmental timing of their social encounters and educational experiences). There was, to be sure, developmental variability within this sample in terms of who initiated an accelerated

path, whether the trajectory was shaped mainly by endogenous vs. exogenous forces, and how it temporally unfolded. However, their stories convey a sense of optimal interplay when we consider how environmental opportunities and challenges were impinged upon them and how resources, tools, and support unleashed their potential and favored their long-term development every step of the way. As shown in Figure 1, we consider the interplay of endogenous and exogenous forces dynamic because developmentally instigative characteristics (e.g., precocity or the autonomous learner) can be dormant unless stimulated and nourished by the environment. In this regard, developmentally optimal conditions provided timely opportunities and support. 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. For example, perseverance, which these individuals demonstrated early on, might not have been crucial in their early education but became critical when they entered the early college entrance program. Likewise, technical and social support (e.g., pedagogy, peer support, and mentorship), which might not be crucial in early years, can be critical in the advanced phase of development. This dynamic is what ECT prescribes as a push-and-sustain mechanism [45] that propels an accelerant's talent development trajectory every step of the way (see Figure 2).

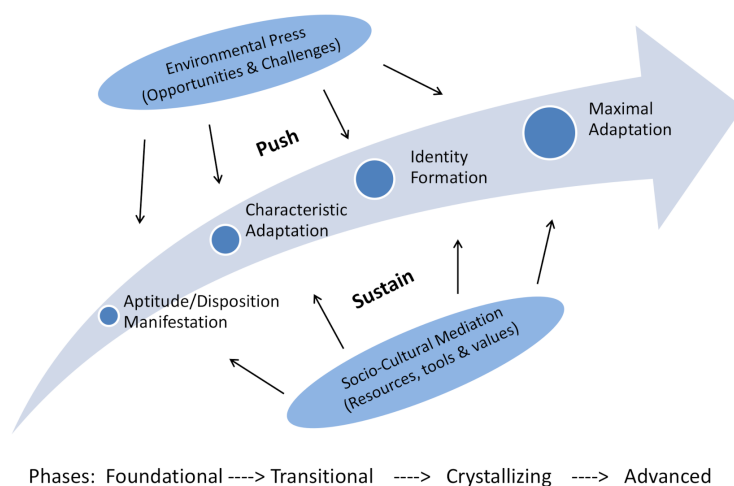


Figure 2. A schematic representation of the evolving complexity theory (ECT) of talent development (Dai, 2017 [45]). Note that the arrow indicates the growth of the person (endogenous factors) while interacting with the two exogenous forces: environmental press and sociocultural mediation.

Note that the model emphasizes the adaptive aspect of talent development in that environmental press pushes the person to adapt and grow, and sociocultural forces sustain the adaptive effort and growing power, leading to successful developmental changes (e.g., shifting from characteristic to maximal adaptations). Previous research shows that academic acceleration tends to produce additional knowledge gains [8]. In light of ECT, we argue that the main benefit of accelerated learning, especially during the early college years, is the early start of a scientific career due to a critical developmental transition.

An earlier study on the SCGY program [26] indicated that many SCGYers experienced a critical transition from being a good student (characteristic adaptation) to living up to much higher standards as an aspiring scientist (maximal adaptation). “Characteristic adaptation” refers to characteristic ways the individual responds to, and acts upon, given environmental opportunities and challenges. As mentioned, all the interviewees in the present study can be characterized as well-adjusted, good students who are on top of their game in the STEM program (i.e., characteristic adaptation). However, “maximal adaptation” means a concerted effort on the part of the learner 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). The ten SCGYers also reported that they gained deep learning experiences and significant amounts of productive experiences with lab

research and year-long internships and mentorship programs with cutting-edge researchers, some of which facilitated their admission to prestigious doctoral programs. Thus, we can attribute the accelerated scientific career of these individuals to the early start of advanced learning and rigorous professional training (i.e., maximal adaptation) compared to their regular same-age peers who were still mastering textbook materials and doing schoolwork in high school.

As mentioned earlier, the selected group of early entrants were among the best of the best in academic acceleration in general and early college entrance programs in particular. If we use our previous study with a cohort of the SCGY class (68% of the entire cohort participated in the study; [26]) for comparison, the 10 students in this study would be placed as the top ten students in the cohort. This suggests the dynamic interplay entails both endogenous and exogenous factors; without endogenous factors, exogenous factors alone cannot do as much, and vice versa. More specifically, having a high IQ might be advantageous for all these early entrants in secondary school but may not be a sufficient condition for academic success when facing a new level of challenge in college and beyond. Personality and motivational qualities as identified in this study may become more essential when dealing with setbacks and obstacles.

Related to the early transition discussed above is a theoretically interesting question of whether academic acceleration in STEM subjects, compared to the social sciences or humanities, is particularly viable for scientifically talented teenagers. The underlying logic is that these disciplines are formal and technical in nature and do not require a lot of social experience and maturity. Jung et al. [57] 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, the social sciences. We further argue, based on the present study as well as past research on age and achievement [9,58,59], that the early start of a scientific research career is conducive to creativity and productivity due to a developmental advantage; for the ten individuals in question, the enduring experience with their respective disciplines, skill sets, and expertise they developed and creative energy at a younger age came together at the right developmental timing (in their mid-twenties) to allow them to flourish professionally at a much earlier age. For that matter, the quality education experiences they obtained over time in the United States as well as China, the access to cutting-edge labs, having leading scientists as mentors (almost all these interviewees pursued doctoral degrees at first-tier universities such as Harvard and Stanford), and even the prestige of the SCGY were all contributing factors.

4.2. Limitations and Implications for Research and Practice

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

That said, we also recognize that many explanations and theoretical arguments, although grounded in data, are still tentative, subject to further investigation. However, we should point out quickly that the explanations we provided earlier were also informed by the preponderance of extant research on the topic, including our previous research [26,37]. Evidence obtained from this study also substantiated many theoretical arguments made in the evolving complexity theory of talent development [45], which integrates a wide range of empirical evidence [60]. Interestingly, although the participants in the present study all grew up and completed their primary, secondary, and tertiary education (SCGY program) before going to the United States for advanced studies, what we found on their acceleration experiences and developmental outcomes was surprisingly similar to what was found in Western countries (see [4,5]). Future studies in different social and cultural contexts can further test

the conjectures and observations made in this study. With a larger sample across multiple contexts, researchers should be able to extend the findings and refine the conjectures and arguments made in the present study. With a quantitative design, a control (comparison) group can be used to confirm and strengthen some of the claims about the importance of the endogenous and exogenous forces identified and stressed in the present study.

The 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, and what needs to be in place in terms of resources and support to ensure success (i.e., the right person in the right place at the right time). The present study yields useful insights regarding these issues. The most important implication of our findings is that it is not sufficient to merely claim that academic acceleration works; it is probably more important to specify the conditions, endogenous as well as exogenous, that make acceleration successful. More specifically, these conditions may be time-sensitive, that is, responsive to specific demands and needs at a particular developmental juncture. For this selected group of early entrants, the milestones they achieved every step of the way mattered to get them that far.

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