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STEM Education

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Abstract

Improving science, technology, engineering, and mathematics (STEM) education, especially for traditionally disadvantaged groups, is widely recognized as pivotal to the United States's long-term economic growth and security. In this article, we review and discuss current research on STEM education in the United States, drawing on recent research in sociology and related fields. The reviewed literature shows that different social factors affect the two major components of STEM education attainment: (*a*) attainment of education in general, and (*b*) attainment of STEM education relative to non-STEM education conditional on educational attainment. Cognitive and social-psychological characteristics matter for both components, as do structural influences at the family, neighborhood, school, and broader cultural levels. However, whereas commonly used measures of socioeconomic status (SES) predict the attainment of general education, social-psychological factors are more important influences on participation and achievement in STEM versus non-STEM education. Domestically, disparities by family SES, race, and gender persist in STEM education. Internationally, American students lag behind those in some countries with fewer economic resources. Explanations for group disparities within the United States and the mediocre international ranking of US student performance require more research, a task that is best accomplished through interdisciplinary approaches.

INTRODUCTION

The crucial role of science in a modern society is commonly acknowledged (Pavitt 1996, Xie & Killewald 2012). Its central role in promoting technological innovation and sustained economic growth is not contested. Conversely, scientific progress depends on the strong financial and non-financial support of society as a whole. Social studies of science research (e.g., Ben-David 1971, Price 1986) devoted to elucidating the interplay between science and societal conditions indicate that it is no accident that the United States has led the world both economically and in science, as America's economic strength has been closely linked to its advances in science and technology (Goldin & Katz 2008, NAS et al. 2007, Xie & Killewald 2012). Given this relationship, concern has recently resurfaced that the United States may be losing its lead in science and therefore its economic competitive edge in an ever more globalized world (NAS et al. 2007).

Concern about the state of American science has a number of origins (Xie & Killewald 2012). A primary cause of the pessimism is the widely held perception that science, technology, engineering, and mathematics (STEM) education in the United States is woefully inadequate, in both quantity and quality, and unequally available across social groups. In this article, we review and discuss current research on STEM education in the United States, drawing on recent research in sociology and related fields.

DEFINING STEM EDUCATION

The acronym STEM is commonly used to reference a set of educational and occupational fields or domains related to science, but there is inconsistency in the definition of this set and debate about whether the four fields deserve special attention as a collective entity (Gonzalez & Kuenzi 2012). In particular, what is considered STEM education varies enormously by educational level (Breiner et al. 2012), and this variance is reflected in our review. At the foundational K-6 level, STEM education is synonymous with the math and science curriculum that is required for all students, so research on STEM education at the elementary school level focuses on participation and performance in science and math in general. STEM education is defined more specifically as the curriculum becomes increasingly specialized at progressive levels of education. For example, in grades 8–12 multiple tracks through the required math and science curriculum become available to students, as do elective courses in the social sciences (e.g., psychology), computer science, and applied topics in engineering and technology (NGSS 2015). Undergraduate and graduate education is designed around sequences of courses in specific fields that can be defined as STEM or non-STEM, but the educational experiences and outcomes vary so significantly across specific fields that researchers need to differentiate among the specific fields considered STEM (Xie & Killewald 2012, Xie & Shauman 2003).

There are two general approaches to defining STEM education. The first is to include education in any field defined as STEM. This approach lumps together many disparate disciplines on the assumption that their shared importance promotes technological innovation, competitiveness, and long-term national prosperity and security (NAS et al. 2007). It does not address the question of what constitutes a STEM field. For example, whereas social science is considered STEM by the National Science Foundation (NSF), it is excluded from the definition used by US Immigration and Customs Enforcement for deciding special visas intended for foreign professional workers in STEM fields (Gonzalez & Kuenzi 2012). The second approach is to emphasize logical and conceptual connections across different STEM fields to treat STEM education as a whole (Honey et al. 2014). This definition calls for curriculum and pedagogical coherence across different STEM fields. The new Next Generation Science Standards (NGSS 2015) now being adopted for K-12 education nationwide reflects this perspective.

One way we can overcome the confusion about the definition of STEM education is to be specific in empirical studies. Many sociological studies take this approach. That is, a study may be concerned with academic achievement or degree attainment in a specific STEM field, e.g., mathematics. Studies that focus further along the education trajectory require researchers to be more specific about fields of study. In precollege years, a researcher is typically concerned with achievement in a broadly defined subject, such as mathematics, and commonly uses measures such as standardized test scores or course grades. At the undergraduate and graduate levels, a researcher is typically concerned with participation in specific majors, achievement in specific courses, and attainment of degrees in specific fields considered part of STEM (Xie & Killewald 2012, Xie & Shauman 2003). In our review of the literature, we follow this practice of being specific whenever possible.

SIGNIFICANCE OF STEM EDUCATION

Sociological research on STEM education takes place at the border between the sociologies of science and education. The sociology of science focuses on science as an important, somewhat unique social institution. In contrast, the sociology of education studies the acquisition of both general knowledge and educational credentials as outcomes of social, familial, and institutional influences.

Science occupations are high status and reward their incumbents with relatively high personal income and social prestige (Rothwell 2013, Xie & Killewald 2012). In addition, as Merton [1973 (1942)] hypothesized, science has long subscribed to a norm unique among high-status occupations: universalism. This means that universalistic (or meritocratic) criteria, rather than functionally irrelevant factors, such as gender, race, national origin, or religious affiliation, are ideally used to evaluate a scientist's performance. This implies that STEM education may be more universalistic than non-STEM education, in that a student's achievement may be evaluated more objectively in a STEM subject than in a non-STEM subject. If so, then STEM education can be viewed as a channel for individual social mobility, allowing socially disadvantaged persons to succeed through objectively measured criteria accepted by STEM educators and scientists (Xie & Killewald 2012; Y. Xie, unpublished manuscript). Indeed, this explanation has been proposed to account for the overrepresentation of Asian Americans in science and engineering since World War II (Xie & Goyette 2003).

STEM education, however, is embedded in the general education system and subjected to its dynamics. A vast literature in economics treats education as a form of human capital that yields substantial economic returns (Card 1999, Mincer 1974) which have increased significantly in recent decades, especially for the highly educated (Autor et al. 2008). STEM education in particular carries a premium in the overall labor market (Rothwell 2013), although the earnings of basic scientists have stagnated in recent decades (Xie & Killewald 2012). Yet an extensive literature in sociology on education stratification affirms that educational attainment is highly dependent on social characteristics, including but not limited to family socioeconomic status (SES) (Blau & Duncan 1967, Sewell et al. 1969), race and ethnicity (Fischer et al. 1996), family structure (McLanahan & Sandefur 1994), sibship size (Blake 1981), schools (Raudenbush & Bryk 1986), and neighborhood (Harding 2003).

DECOMPOSITION OF STEM EDUCATION

To understand STEM education, therefore, we need to recognize that it is both influenced by the many social forces that shape general educational outcomes in American society, and subject to the distinct characteristics of and influences on science as a separate institution. We therefore organize this review around these two major components of STEM education attainment: (*a*) attainment of education in general, and (*b*) attainment of STEM education relative to non-STEM education conditional on educational attainment. This decomposition does not reflect real social processes, as students, parents, and teachers in reality do not necessarily separate STEM from general education. Yet this decomposition is analytically useful because it reflects how past research has been organized as well as the empirical evidence that the social processes underlying attainment of general and STEM education are somewhat distinct (Xie & Killewald 2012, Xie & Shauman 2003).

Science always requires education, but education does not have to be scientific. Over the last century, education, especially postsecondary education, has become an increasingly important determinant of life chances and lifestyles in the United States (Fischer & Hout 2006). Large literatures in economics and sociology attempt to explain why individuals attain education. Economics sees educational attainment as a rational economic investment that is undertaken because it yields economic returns, i.e., higher earnings (Becker 1964, Willis & Rosen 1979). Sociology treats education as a mechanism by which families transmit social advantages or disadvantages to the next generation (Blau & Duncan 1967, Raftery & Hout 1993, Sewell et al. 1969), and considers how the cultural norms inherent in social class background affect educational experiences and attainment (Boudon 1974, Bourdieu 1977, Bowles & Gintis 1976, Brand & Xie 2010).

STEM education is special because it is required for science or engineering employment. Although it is possible, indeed it is common, for someone with STEM education to pursue a career outside of science and engineering, it is very difficult for someone without STEM education to pursue a STEM career. There are good reasons to believe that the social determinants of STEM education, like the determinants of science careers, are different from those of general education (Xie & Killewald 2012, Xie & Shauman 2003; Y. Xie, unpublished manuscript).

Hence, we propose a decomposition approach to understanding STEM education. First, we ask what social determinants and processes affect educational attainment in general. Second, we ask what social determinants and processes affect attainment of STEM education relative to non-STEM education conditional on attainment of general educational. The second component is analogous to horizontal stratification in postsecondary education (Gerber & Cheung 2008). This approach admittedly works better at the college than at the precollege level, because mathematics and science are inseparable from general education in the elementary and secondary curriculum. Students begin to specialize into disciplinary tracks at the college level, and only a small fraction chooses STEM fields (Xie & Killewald 2012, Xie & Shauman 2003). This decomposition helps organize the different strands of the literature relevant to STEM education, so we apply it as a general framework for this review.

SOCIAL DETERMINANTS OF EDUCATION IN GENERAL

We briefly review the literature on the social determinants of educational attainment to frame our review of the influences on STEM educational attainment. Many comprehensive reviews of research on educational attainment and stratification are available for readers seeking more complete overviews (Bowles & Gintis 1976, Buchmann et al. 2008, Grodsky et al. 2008, Hallinan 1988, Kao & Thompson 2003).

Contextual Factors

Student outcomes are dependent on the characteristics of the social settings in which the students are situated. The study of educational attainment has largely examined the effects of factors operating at two somewhat overlapping contexts: residential neighborhood and school.

Studies document that neighborhood disadvantage, commonly measured using such contextual variables as neighborhood-level poverty rate, affects children's cognitive ability (Brooks-Gunn et al. 1993, Sharkey & Elwert 2011), verbal ability (Sampson et al. 2008), academic achievement (Sastry & Pebly 2010), and high school graduation (Harding 2003). Even more concerning is evidence that residential segregation by family income has substantially increased in the past three decades (Reardon & Bischoff 2011), placing children living in poor neighborhoods at a severe disadvantage in educational attainment (Reardon 2011). Along with socioeconomic segregation, racial segregation in America has long been known to severely disadvantage Black Americans (Massey 1993) because it concentrates them in poor and disadvantaged neighborhoods.

Young people spend more waking hours in school than in any other setting, and sociologists have long been interested in the effects of school characteristics on achievement and identity formation (Coleman 1968). Many studies demonstrate that school characteristics affect students' academic outcomes (Hedges et al. 1994, Greenwald et al. 1996, Lauen & Gaddis 2013, Raudenbush & Bryk 1986), although the causal mechanisms driving the associations and the degree to which the effects operate through schools' economic resources (e.g., Hanushek 1989) have yet to be fully identified. Net of family-level factors, school-level effects are found inconsistently but indicate that school resources matter. Small classroom size significantly improves students' academic achievement (Krueger 2003), and comparisons of academic growth in summer versus nonsummer months show that schools may reduce inequalities associated with family SES (Downey et al. 2004). But inequalities by race appear more resistant to school resources (Downey et al. 2004), and schools may reinforce inequalities through curricular tracking (Gamoran & Mare 1989). The complex influence of school context is illustrated by studies showing that the academic performance of low-income students, particularly Black and Latino students, may be negatively affected by the proportion of middle- and upper-class students in the schools they attend (Crosnoe 2009).

Teachers, a fundamental school resource, are believed to influence students' educational outcomes. The influence of teachers, however, figures more prominently in personal accounts and qualitative research than in quantitative analyses because the influences are likely specific to individual teachers and thus hard to quantify and distinguish from potential confounders. A conventional method is to measure teacher quality with teacher's observed characteristics such as age, degree, teaching experience, professional training, and salary (Ross et al. 2012). Evidence suggests that teacher quality significantly improves students' academic achievement, net of family socioeconomic background (Darling-Hammond 1999, Rockoff 2004, Wayne & Youngs 2003).

Family Influences

The importance of the family for educational outcomes is well established in sociology. The classic Blau & Duncan (1967) and Wisconsin (Hauser et al. 1983, Sewell et al. 1969) models of status attainment codified the influence of parents' education and occupation on the educational attainment of their children. Subsequent analyses have affirmed the classic models and extended them by examining racial differences (Alexander et al. 1994), mediating mechanisms (e.g., Greenman et al. 2011, Hill & Tyson 2009, McLoyd 1998, Roska & Potter 2011), multigenerational influences (Jæger 2012), and how the influence of family changes over time (Reardon 2011). Aspects of family structure, including single-parent headship (Astone & McLanahan 1991, Kim 2011) and number of siblings (Blake 1989, Downey 1995, Steelman et al. 2002), are shown to influence educational outcomes regardless of SES.

A great deal of research focuses on identifying the causal mechanisms through which family influences operate. Studies often pit the direct effect of families' economic resources, i.e., how much parents invest in their children's education and development (Becker 1991, Duncan et al. 1994, Kaushal et al. 2011), against the effects of class-based cultural and social resources, i.e., class-based differences in parenting practices and opportunities for skill-building (Jæger 2011, Lareau 2011, Mayer 1997) and the development of noncognitive "soft" skills as well as cognitive skills (Cunha & Heckman 2009, DiPrete & Jennings 2012, Heckman et al. 2013, Hsin & Xie 2014, Turney & McLanahan 2012). Noncognitive[1] skills include a variety of psychological traits that affect one's behavior toward learning and work. Examples include interest in the subject area, ambition, expectation, conscientiousness, persistence, self-control, and a range of social skills that affect performance in social settings. In addition, the influence of family structure is often interpreted as evidence that social capital (Coleman 1988), i.e., social connections that bring information and emotional support, is the mechanism through which family affects educational outcomes (Dika & Singh 2002). Empirical evidence supports each of these perspectives and indicates that they are interrelated rather than competing. For example, parental beliefs and behaviors may mediate the influence of parental SES, as can practices construed as concerted cultivation (Bodovski & Farkas 2008, Lareau 2011) or, more generally, parental involvement (Jeynes 2005).

Individual-Level Factors

Myriad individual characteristics influence educational outcomes. The important individual-level influences range from cognitive to noncognitive skills, from physical to mental health, and from personality to physical characteristics. Less obvious is the relative degree to which these characteristics are inborn or developed; this nature versus nurture debate has been ongoing in social science since the nineteenth century (Plomin et al. 1994) and is unlikely to be resolved in the foreseeable future. We briefly summarize the research in two broad categories of individual influences: cognitive ability, or intelligence, and social-psychological, or noncognitive, factors. We point readers to Farkas (2003) for a more thorough review of these influences on social stratification processes.

Broadly speaking, cognitive ability refers to aptitude for mental tasks such as problem-solving, comprehension, reasoning, knowledge acquisition, abstract thought, and connection-making. Cognitive ability is strongly associated with children's academic performance (Cain et al. 2004, Deary et al. 2007, Koenig et al. 2008, Rohde & Thompson 2007) and a broad range of educational outcomes, including student performance, university entry and completion, and overall educational attainment (Jencks et al. 1979, Marks 2013) even when socioeconomic background is controlled. Of course, the strong association between cognitive ability and educational outcomes does not settle the nature-nurture debate or the issue of how intelligence is related to social environment (see Nisbett 2009 for an extensive review).

Interest in the influence of noncognitive skills has grown in recent years (Cunha & Heckman 2009, DiPrete & Jennings 2012, Heckman et al. 2013, Hsin & Xie 2014, Turney & McLanahan 2012). However, stratification researchers in sociology have long studied the role of psychological traits in socioeconomic achievement. The classic Wisconsin model highlights the importance of future educational and occupational expectations as predictors of future educational success (Hauser et al. 1983, Sewell et al. 1969). Others have added attention and responsiveness to performance feedback (Alexander et al. 1994) and self-discipline (Duckworth & Seligman 2005) to the list. There is some evidence that the enhancement of children's noncognitive rather than cognitive skills is the primary driver of later life benefits of early educational interventions for at-risk children (Heckman et al. 2013).

[1]The word "noncognitive" may be misleading because the formation of these attitudes and their influences on behaviors surely involve cognition. The term is now commonly used in economics and sociology.

SOCIAL DETERMINANTS OF STEM VERSUS NON-STEM IN EDUCATION

In this section we examine how the set of factors known to affect general education is related to involvement and achievement in STEM education.

Contextual Factors

Social and institutional environments matter for STEM educational outcomes just as they do for general education, but research on the influential contextual factors for STEM education has narrowly focused on school-specific factors expected to affect participation and achievement in STEM education. Thus, although there is evidence that neighborhood disadvantage, for example, is associated with lower math achievement in primary school (e.g., Catsambis & Beveridge 2001, Greenman et al. 2011), little is known about other potential contextual factors, such as local labor market characteristics or proximity to science-focused industry.

Schools differ widely in resources for STEM education, such as teacher quality and science laboratories, primarily reflecting cross-school inequalities in family and neighborhood SES.[2] Studies of elementary and secondary schools suggest that funding and resource availability shapes the extent to which students engage in and excel at STEM education (Museus et al. 2011, Oakes 1990, Wang 2013). The current research focuses largely on the structural effect of resources: Well-resourced schools offer relatively wide arrays of math and sciences courses and greater access to resources (Oakes & Saunders 2004), but their effect on learning cultures or promotion of STEM education has receive much less attention (Legewie & DiPrete 2014b, Wang 2013). School resources are also positively associated with staffing of high-quality teachers (Clotfelter et al. 2005, Goldring et al. 2013). Numerous studies show that access to knowledgeable and experienced math and science teachers positively impacts both student learning (Darling-Hammond 1999, Hattie 2008, Hill et al. 2005, Sadler et al. 2013, Wayne & Youngs 2003) and student interest in and passion for science (Maltese & Tai 2011, Osborne et al. 2003, Sjaastad 2012, Tytler & Osborne 2012, Woolnough 1994). Although the studies often suffer from potential confounders (e.g., selection), they collectively provide compelling evidence that school context predicts achievement in STEM education.

Higher-education research similarly shows that characteristics of institutional context and climate affect students' pursuit of and persistence in a STEM major (Chang et al. 2014, Hurtado & Carter 1997, Seymour & Hewitt 1997). Unsupportive campus climates, highly competitive classrooms, poor instruction, and excessive workloads can diminish academic engagement, achievement, and persistence toward a degree (Cabrera et al. 1999; Carlone & Johnson 2007; Chang et al. 2011, 2014; Seymour & Hewitt 1997). These negative contextual characteristics may be more common in STEM coursework than in non-STEM coursework, particularly in introductory or weeder classes (Seymour & Hewitt 1997) and in selective universities than in nonselective universities (Chang et al. 2008), pushing otherwise capable and interested students toward non-STEM majors (Carlone & Johnson 2007, Chang et al. 2011) or out of postsecondary education altogether (Hurtado & Carter 1997). Postsecondary environments in which students receive engaging instruction, encouragement from faculty and other students, sufficient financial aid and networking opportunities are positively associated with STEM engagement and persistence (Chang et al. 2011, Graham et al. 2013, Museus et al. 2011, Seymour & Hewitt 1997). The opportunity to collaborate with faculty on undergraduate research projects may be especially effective for building a student's confidence and identification with the scientific community (Chang et al. 2011, Graham

[2] Research shows that rural schools do not lag behind urban schools in math education (Provasnik 2007).

et al. 2013, Grandy 1998). More importantly, these programmatic investments may improve the persistence of students in STEM college majors.

Moving forward, further research is needed to identify institutional factors that causally promote students' engagement with and achievement in STEM education. It is particularly necessary to refrain from interpreting as causal the observed associations of institutional characteristics with students' outcomes in STEM education, for they may be confounded by the selective sorting of students into different institutions. Once causal mechanisms are known, effective policies may be formulated to promote STEM education. Further, it will be fruitful to know how institutional factors affect STEM education versus non-STEM education, conditional upon their effects on general education.

Family Factors

As with general education, family factors—particularly family SES—are strongly associated with students' achievement in math and science, interest in STEM higher education, and attainment of a STEM degree. Recent reports and studies drawing on current data confirm this relationship: Substantial differences in STEM coursework participation and achievement persist between students from low-SES and high-SES backgrounds throughout the STEM pipeline (Miller & Kimmel 2012, Mulligan et al. 2012, NSB 2014, Schneider et al. 1998). But the specific mechanisms through which family SES influences STEM education are no clearer than they are for general education.

One prominent explanation posits that the relatively high levels of education and income that characterize middle- and high-SES families enable them to provide their children with the encouragement, support, exposure to science, and access to STEM enrichment experiences necessary to develop and sustain early interest, confidence, and aspirations in STEM (Archer et al. 2012, Dabney et al. 2013, Harackiewicz et al. 2012, Sjaastad 2012, Turner et al. 2004). Some researchers further suggest that middle-class parenting strategies and resources may promote a worldview that enables children to view science as a thinkable/natural career choice (Archer et al. 2012). The family influence on youths' social-psychological orientation may be particularly important for promoting math and science achievement and persistence in the STEM pipeline (Mau 2003, Tai et al. 2006, Wang 2013; see below for further discussion).

Although there is clear empirical evidence that family background affects STEM engagement and achievement early in the life course, it is unclear how far into the educational and/or career trajectory such effects extend. Descriptive analyses suggest that SES continues to exert an important influence well beyond primary and secondary school, because high-SES students make up a disproportionate percentage of those obtaining STEM degrees and pursuing STEM careers (Chen 2009, Ware & Lee 1988). But these results are confounded by the fact that high-SES students are more likely to matriculate and complete college. Multivariate analyses show that differences by family socioeconomic background in STEM interest and persistence during postsecondary education disappear when other factors, such as academic achievement, are controlled (Chen & Soldner 2014, Ma 2009, Mau 2003, Xie & Killewald 2012). Thus, recent research suggests that family background plays an influential role in acquiring the academic skills necessary to attain a postsecondary degree but it does not play a direct role in the pursuit and attainment of a STEM degree specifically.

The field will benefit from more research attempting to understand the specific mechanisms through which family background impacts STEM engagement, particularly at a young age. As we have argued, this appears to be the period in which family background exerts a particularly strong effect on STEM education. Researchers should also further explore how family influences may be highly heterogeneous—varying across different families, say, by family-level characteristics beyond what are usually captured in conventional SES measures, such as cultural values, parent-child relations, or individual-level characteristics (discussed below).

Individual Factors

Individual cognitive ability, spatial ability, numeracy, or other indicators of basic cognitive functions (Spelke 2005) are all closely correlated with both achievement in math and science courses in compulsory and postsecondary education and scores on standardized math and science tests (Deary et al. 2007, Lynn & Mikk 2009, Reilly & Neumann 2013, Wai et al. 2010). Spatial thinking is assumed to be an important determinant of achievement in STEM education; it has also been linked to interest and confidence in math and science (Wai et al. 2010). However, the assumption that spatial and quantitative aptitude are uniquely essential prerequisites for achievement in STEM is not without critics (see Spelke 2005), nor is the assumption that individual capacity for these cognitive skills is innate and fixed. A growing body of research examines the malleability of fundamental cognitive skills such as spatial thinking (e.g., Newcombe 2010) and points to new areas for investigation.

Researchers now recognize particular individual social-psychological characteristics strongly related to engagement and achievement in STEM education (e.g., Maltese & Tai 2011, Tai et al. 2006, Wang 2013). These include math and science self-concept, interest in science, and aspirations for a science-related career. Science self-concept, or self-reflexive beliefs about one's math and science abilities, predicts participation in challenging STEM courses, pursuit, persistence and attainment of STEM degrees, and entrance into STEM careers (Cech et al. 2011, Correll 2001, Mau 2003, Maltese & Tai 2011, Wang 2013). Interest in math/science or aspirations for a STEM-type career are strongly predictive of STEM educational outcomes (Maltese & Tai 2010, 2011; Maple & Stage 1991; Mau 2003; Tai et al. 2006; Xie & Killewald 2012; Xie & Shauman 2003). In particular, aspiring to a career in science appears to be a prerequisite for attaining a STEM degree (Tai et al. 2006, Xie & Shauman 2003), and loss of interest is a main reason for attrition from STEM majors (Seymour & Hewitt 1997). In addition, researchers have recently defined the concept of science identity—the sense that science is right for an individual, or that an individual is right for science—and recognized its impact on STEM educational outcomes (Archer et al. 2012, Cech et al. 2011, Cole & Espinoza 2008, Perez et al. 2014). Science identity is hypothesized to form early and to influence engagement with STEM education and careers throughout the life course (Archer et al. 2012, Cech et al. 2011, Perez et al. 2014). The fact that each of these noncognitive influences remains significant even after controlling for academic achievement (Cech et al. 2011, Simpkins et al. 2006, Wang 2013, Xie & Shauman 2003) attests to the significance of affective, or psychosocial, influences on STEM educational outcomes. Continued research on the social-psychological determinants of STEM education, particularly as they emerge and evolve over the life course, will shed new light on individual differences in STEM education—why certain people and groups excel in STEM education, whereas others do not.

INTERNATIONAL COMPARISONS OF STEM EDUCATION

Comparing STEM education in the United States with that in other countries is a complicated matter to which both the public and policy circles have paid a great deal of attention. These comparisons have been sparked by the relatively mediocre performance of American students on international standardized mathematics and science tests (Hanushek et al. 2010, Kelly et al. 2013, Killewald & Xie 2013, NSB 2014, OECD 2010, Provasnik et al. 2011). The disappointing performance of US students is surprising to many, given the wealth of the United States relative to that of many better-performing countries, such as Taiwan, Finland, and Hungary (Hanushek et al. 2010, Killewald & Xie 2013). The surprise and public outcry also stem from the belief that the United States has been the world leader in science for more than 80 years (Xie & Killewald 2012). How could other countries beat the United States at its own game? Given US students' mediocre test performances, will the United States remain competitive in science and the knowledge-driven economy? Worrisome speculation about these questions popularized the report *Rising Above the Gathering Storm* (NAS et al. 2007) and prompted renewed attention to STEM education in the United States.

A review of the large literature on international comparison of STEM education is beyond the scope of this article. Interested readers can find discussions in the NAS et al. (2007) report as well as responses by Killewald & Xie (2013) and Xie & Killewald (2012). Many studies that explore the achievement differences between the United States and higher-performing countries find that US students are disadvantaged on many factors that affect math and science achievement. These factors include national cultural traditions related to math and science (Cogan & Schmidt 2002, Fang et al. 2013, Stevenson & Stigler 1992), family and school support for and emphasis on math and science education (Fuchs & Wößmann 2007, Sousa et al. 2012, Tsui 2005), structure of the educational system and national labor market conditions (Langen & Dekkers 2005), and cross-country differences in teaching style and curriculum (Gonzales et al. 2000, Roth et al. 2006, Schmidt 2012).

GENDER AND STEM EDUCATION

Despite robust progress toward equity, gender disparities continue to be a defining characteristic of STEM education. In this section, we review the trends in the gender gaps in STEM achievement, participation, and interest and synthesize the research aimed at explaining these gaps.

Gender Gaps in STEM Achievement

Achievement is commonly measured with standardized test scores and course grades in math and science. Studies have long shown that female students' math and science grades are equal to or better than those of their male classmates throughout elementary and secondary school (Kenney-Benson et al. 2006, Shettle et al. 2007). Early studies of standardized test performance also showed gender parity, or a slight female advantage, in basic computation and understanding of math concepts throughout grades K-12 (Hedges & Nowell 1995, Hyde et al. 1990a). Yet gender gaps in three aspects of achievement dominate the perception of gender and STEM and are often cited as evidence of innate male superiority in STEM education (Correll 2001, Hyde 2005, Nosek et al. 2002): (*a*) male advantage in complex problem-solving skills during high school (Hyde et al. 1990a), (*b*) greater variability in males' test scores and a resulting preponderance of boys among the highest scorers (Ellison & Swanson 2010, Hedges & Nowell 1995, Penner 2008, Penner & Paret 2008, Robertson et al. 2010, Wai et al. 2010, Xie & Shauman 2003), and (*c*) male advantage on spatial abilities (Halpern et al. 2007, Hyde 2005, Linn & Petersen 1985, Spelke 2005).

Recent analyses challenge the ideas that the observed gender gaps in STEM achievement are immutable and that they are socially significant. There has been a secular decline in the overrepresentation of males in the upper tail of the achievement distributions (Hyde & Mertz 2009, Hyde et al. 2008, Lindberg et al. 2010) and the presence and size of the upper tail disparity vary substantially across countries, race, and SES (Penner 2008, Penner & Paret 2008). In-depth studies of spatial abilities document female (as well as male) advantages on specific tasks, that all gaps are consistently small, and that performance on all tasks is sensitive to training (Halpern et al.

2007, Hyde 2005, Spelke 2005). The social significance of the documented gender disparities in achievement remains unclear, as these disparities have limited power to explain disparities in STEM participation (Weinberger 2005, Xie & Shauman 2003). Commonly used standardized tests may be poor instruments for measuring gender differences in STEM aptitude (Gallagher et al. 2002, Halpern 2002), because research suggests that item content may bias the scores (Chipman 2005, Spelke 2005) and that such tests have limited power to predict actual task performance and STEM achievement for girls (Schmidt 2011). Research also highlights the need to estimate the potential influence of math or science achievement in relation to achievement in other domains (Lubinski & Benbow 2006, Riegle-Crumb et al. 2012, Wang et al. 2013).

Gender Gaps in STEM Participation

Participation in STEM education is conventionally measured in terms of high school math and science course completion and postsecondary choice of major and degree field, and the size of the gender gap varies across these measures. Gender gaps in high school math participation have disappeared, as female students are now more likely than their male peers to complete precalculus and algebra II and are equally likely to complete calculus (NSB 2012, 2014). In high school science, girls continue to be overrepresented in advanced biology and underrepresented in physics, but these completion disparities have declined significantly (NSB 2012, 2014). Despite growing equality in high school coursework, however, wide gaps in STEM participation remain in tertiary education. Thus far, growth in women's participation in STEM majors has been driven mainly by the general increasing enrollment of women (Mann & DiPrete 2013) and declining gender gaps in persistence in the science pipeline during college and into postbaccalaureate education (Miller & Wai 2015). Consequently, whereas the number of women earning undergraduate and graduate degrees in STEM fields has steadily increased, the proportionate representation of women in many STEM fields has not increased since the 1980s (Catsambis 1994, DiPrete & Buchmann 2013, England & Li 2006, England et al. 2007, Mann & DiPrete 2013) and may be declining in some engineering fields (Mann & DiPrete 2013). Women in the United States and other industrialized countries have earned the majority of biological and social science degrees since the 1980s, but they remain significantly underrepresented among degree recipients in engineering, the physical sciences, math, and computer science (Charles & Bradley 2002, 2006, 2009; DiPrete & Buchmann 2013; Xie & Killewald 2012; Xie & Shauman 2003).

Completion of advanced math and science classes remains one of the strongest predictors of students' scores on achievement tests and pursuit of postsecondary STEM degrees (Bozick & Lauff 2007, Chen 2009, Xie & Shauman 2003). But the association between secondary STEM course completion and grades and postsecondary STEM participation is much stronger for males than for females (Mann & DiPrete 2013, Morgan et al. 2013, Riegle-Crumb et al. 2012, Xie & Shauman 2003); i.e., gender parity in preparation does not translate into gender parity in persistence in STEM education. The continuing gender gaps in postsecondary STEM education suggests that we do not yet fully understand the processes that promote persistence in STEM education and how those processes vary by gender. This ignorance highlights a need for empirical assessments of the qualitative aspects of participation, i.e., of the in-class interactions and experiences that may generate or reinforce gender disparities among young women and men who are equally prepared to pursue postsecondary STEM education but do so at very unequal rates.

Gender Gaps in STEM Interest and Affect

In contrast to the trend toward gender equality in math/science achievement and STEM participation in many domains, significant gaps in math/science interest and affect endure. The notion that males are naturally more talented and interested in science is a widespread cultural stereotype (Leslie et al. 2015, Nosek et al. 2009), and although most people consciously reject it (Hyde et al. 1990b), implicit association studies confirm the ubiquity of the "math = male" stereotype across age, race/ethnicity, gender, and country (Cvencek et al. 2011; Kiefer & Sekaquaptewa 2007; Nosek et al. 2002, 2009). Reflecting this normative belief, girls consistently report lower self-assessments of quantitative skills, lower self-confidence in math abilities, less interest and less motivation to learn math and science, and higher levels of math anxiety than their male peers, as well as less interest in pursuing careers in STEM fields, even after controlling for achievement (Correll 2001, 2004; Else-Quest et al. 2010; Fredricks & Eccles 2002; Jacobs et al. 2006; Riegle-Crumb et al. 2011; Sadler et al. 2012; Wang et al. 2013; Watt 2004, 2006). Girls also are more likely than boys to express interest in pursuing people-oriented work, to see science as inconsistent with that orientation, and to perceive the scientific lifestyle as unattractive (Miller et al. 2006).

Gender disparities in social-psychological determinants of STEM education manifest in consequential ways at the more advanced levels of education. For example, Cech et al. (2011) find that among college engineering majors, women have lesser "professional role confidence" than men do. In addition to the gender gaps in STEM-specific affect, recent scholarship shows how disparities in seemingly unrelated affective characteristics, such as the relative female aversion to competition (Gneezy & Rustichini 2004, Gneezy et al. 2003, Niederle & Vesterlund 2007) and risk-taking (Croson & Gneezy 2009), contribute to gender gaps in STEM education (Alon & DiPrete 2013, Niederle & Vesterlund 2010).

Explanations for the Gender Gaps in STEM Education

Early literature often attributed gender gaps in postsecondary STEM education to gender differences in precollege math and science achievement and participation. As the gaps in test scores and course-taking closed, this explanation lost its power (Morgan et al. 2013, Riegle-Crumb et al. 2012, Xie & Shauman 2003). Despite the perennial quest for biologically based gender differences in science and math aptitudes (Baron-Cohen 2003, Ceci & Williams 2010, Ceci et al. 2009, Valla & Ceci 2011), essentialist "innate ability" explanations have been undermined by a large body of empirical work (Ceci et al. 2009, Hyde 2005, Spelke 2005). Over the past decade, the effort to explain gender inequities in STEM education has focused increasingly on the determinants and influence of interest in science and math as the primary factors affecting sex differences in STEM education. Early life course interest in STEM is strongly associated with participation in STEM education (Tai et al. 2006), and the large gender gap in STEM interest during high school is strongly associated with the gender gap in postsecondary STEM education (Legewie & DiPrete 2014a, Ma 2011, Perez-Felkner et al. 2012, Sadler et al. 2012, Xie & Shauman 2003). What, then, explains the gender gap in interest in STEM education?

Essentialist explanations posit that the interest gap is a natural outgrowth of biologically based sex-typed predispositions. One prominent theory argues that prenatal hormonal exposure predisposes females to a natural affinity for interacting with people and caring relationships and males to an innate interest in inanimate, technical, and mechanical things (Baron-Cohen 2003, Schmidt 2011, Su et al. 2009). Another theory posits that the interest gap is linked to the biological requisites of childbearing, which cause females to naturally prioritize family over work roles (Ceci & Williams 2010, 2011; Ceci et al. 2009). Recent scholarship does not support these essentialist explanations. Research shows that interest in STEM is highly responsive to environmental influences (Cheryan et al. 2009, 2011; Murphy et al. 2007; Stout et al. 2011). Scholars have raised questions concerning the validity and reliability of measures commonly used in this line of research, such as the person-thing construct and similar bipolar interest scales (e.g., data-ideas) (Tay et al. 2011, Valian 2014). Further, although gender differences in work-life preferences are pervasive, they do not explain gender gaps in STEM interest or participation (Cech et al. 2011; Frome et al. 2006, 2008; Mann & DiPrete 2013; Morgan et al. 2013; Perez-Felkner et al. 2012; Riegle-Crumb et al. 2012; Xie & Shauman 2003).

Social-psychological and sociocultural perspectives offer more nuanced explanations for the interest gap. For example, expectancy-value and expectation-states theories emphasize the influence of cultural milieu, the interactional nature of interest formation and persistence, and the cumulative influence of these processes on both individual outcomes and structures of opportunity in STEM education (Eccles 2011a,b, Ridgeway 2014, Ridgeway & Correll 2004, Shepherd 2011). Extensive analyses of cross-national data confirm the importance of cultural beliefs as predicted by these theories: Gender gaps in STEM achievement, interest, and postsecondary participation are strongly associated with national-level measures of adherence to implicit male = math stereotypes (Nosek et al. 2009) and gender-essentialist ideology (Charles & Bradley 2009, Charles et al. 2014) as well as indicators of social and economic gender equity (Else-Quest et al. 2010, Guiso et al. 2008, Penner 2008). Studies indicate that macro-level cultural conditions affect gender differences in STEM interest through a variety of causal mechanisms: They are encoded in and conveyed through parents', teachers', and significant others' attitudes and expectations (Fredricks & Eccles 2002; Herbert & Stipek 2005; Jacobs et al. 2005, 2006; Lavy & Sand 2015; Riegle-Crumb & Humphries 2012), pervasive cultural cues about scientists (Beilock et al. 2010; Cheryan et al. 2009, 2011; Murphy et al. 2007; Stout et al. 2011), the dearth of positive female role models and mentors (Carrell et al. 2010), and school environments and friend networks (Legewie & DiPrete 2014b, Riegle-Crumb et al. 2006).

The causal link between cultural beliefs and STEM interest is well demonstrated in studies of stereotype and identity threat (Aronson & McGlone 2008, Nguyen & Ryan 2008, Nosek et al. 2002) and occupational preference formation (Correll 2001, 2004). In particular, expectation-states theory (Ridgeway 2014) posits that cultural stereotypes structure inequality by generating implicit bias in evaluation, association preferences that segregate networks, and interpersonal hostility toward individual members of negatively stereotyped groups. Recent studies document that female students face negative biases in the grading of their school work (Lavy & Sand 2015) and evaluation of their competence and qualification for STEM employment (Knobloch-Westerwick et al. 2013, Moss-Racusin et al. 2012, Reuben et al. 2014), and gender-segregated networks and chilly climates in STEM higher education and workplaces (Koput & Gutek 2010, Logel et al. 2009, Sheltzer & Smith 2014, Steele et al. 2002). Future research should focus more on identifying the nature, timing, and relative impacts of these processes to develop effective practices that foster and sustain interest in STEM among girls and women.

RACIAL AND ETHNIC DIFFERENCES IN STEM EDUCATION

Despite significant gains in the participation of underrepresented minorities (URMs)—Blacks, Hispanics, and Native Americans—in STEM education, they continue to be underrepresented in the STEM pipeline and to lag behind Whites and Asians in STEM and general achievement (Chen & Soldner 2014, NSB 2014).

Racial Gaps in STEM Achievement

Reports indicate that although URMs have made tremendous strides in terms of narrowing the racial gap with Whites and Asians in math and science test scores, course participation, and course grades, significant differences still remain (NCES 2013, Nord et al. 2011). Test score disparities begin to emerge as early as kindergarten and generally become more pronounced as students progress through the school system (Fryer & Levitt 2004, Jencks & Phillips 1998, Reardon 2008). Performance in math and science coursework follows a similar pattern, with Asians and Whites typically earning significantly higher average grades than URMs throughout the school years (Kao & Thompson 2003, Nord et al. 2011). Taken together, these achievement gaps play a major role in limiting the participation of URMs in STEM education (Museus et al. 2011, Riegle-Crumb & King 2010, Xie & Killewald 2012).

The aggregate trends also mask important heterogeneity, which is the subject of a growing body of research on URMs. For example, studies show that URM disadvantage is most pronounced, both in magnitude and in degree of divergence, among high-achieving students (Hedges & Nowell 1999, Neal 2005, Reardon 2008, Riegle-Crumb & Grodsky 2010). Reardon (2008) finds that among elementary-school students, the Black-White gap in math achievement grew twice as fast among high-achieving students as among low-achieving students. The fact that the most talented URMs fall behind the fastest is perhaps more alarming than the aggregate racial gap, given that the high-performing students have the greatest potential to excel in subsequent STEM education. Moreover, it raises important questions about whether these students are receiving access to opportunities and resources needed to keep pace with their peers.

Racial Gaps in STEM Participation

At the K-12 level, URM students tend to take fewer and less challenging math and science courses than their White and Asian peers (Kelly 2009, Nord et al. 2011, NSB 2014, Riegle-Crumb & Grodsky 2010) and are significantly more likely to be placed in remedial and low-track math and science courses (Kao & Thompson 2003, Oakes 1990). The racial/ethnic gap in advanced coursework is strongly associated with racial/ethnic gaps in standardized test performance (Gamoran & Mare 1989, Kao & Thompson 2003) and interest in STEM majors and careers (Miller & Kimmel 2012, Wang 2013). The overrepresentation of URMs in remedial courses reinforces these gaps, as these courses focus on basic knowledge and rote memorization (Kao & Thompson 2003, Oakes 1990).

At the postsecondary level, the number of URMs entering college and obtaining STEM degrees has steadily grown over time. For example, the share of URMs among all recipients of science and engineering bachelor's degrees grew from 17% in 2000 to 20% in 2011 (NSB 2014). Still, URM students are underrepresented because their share in the general population aged 25–29 is much higher, above 36% in 2011 (US Census Bureau 2014). Furthermore, among all holders of STEM degrees, URMs are overrepresented among those who attend two-year and less prestigious four-year institutions (Chen & Soldner 2014, Reardon et al. 2012). In particular, a large proportion of URMs pursue and attain STEM degrees at minority-serving and historically Black colleges and universities (NSB 2014), which often provide a more supportive and welcoming campus climate than traditional universities do (Allen 1992, Hurtado 1992). The implications of the racial/ethnic differences in institutional affiliation are not well understood, but because elite graduate programs and industries disproportionately draw from elite mainstream universities, these differences may have important implications for stratification within graduate school and the workforce.

Racial Gaps in STEM Interest and Affect

Although interest in STEM is highest among Asians (DeWitt et al. 2011, Xie & Goyette 2003), studies at all levels of education indicate that URMs express enthusiasm for STEM education and careers on par with their White peers, despite the former's lower levels of achievement (NSB 2014, Riegle-Crumb & King 2010, Riegle-Crumb et al. 2011). For instance, a report by the National Science Board (NSB 2014) shows that since at least 1995, URM college students have pursued STEM majors at rates comparable to those of White students. Other studies of racial/ethnic differences in affective orientations toward STEM result in similarly paradoxical findings: Although rates of participation and achievement are disproportionately low among URMs, their levels of self-confidence and enjoyment of math and science are disproportionately high (Catsambis 1994, Riegle-Crumb et al. 2011).

Explanations for the Racial Gaps in STEM Education

In general, there are two broad explanations for the racial disparities in STEM education. The first explanation attributes the gaps to URM students' lower levels of interest in and enjoyment of science. As we have already demonstrated, we find little evidence to support this hypothesis. Instead, mounting evidence suggests that social-psychological factors may limit the extent to which URM students are able to convert their interests to meaningful STEM engagement. For example, studies show that although adolescent URMs express a level of interest in science that resembles that of their White peers (Riegle-Crumb et al. 2011), URM youth lack opportunities and family resources to develop a deep connection with science (Archer et al. 2012, Aschbacher et al. 2010).

Social-psychological factors may become even more important during postsecondary education, since individual choice plays a larger role in persistence at this educational stage. Studies reveal that URM students in STEM majors at the postsecondary level often struggle with feelings of isolation (Seymour & Hewitt 1997) and have difficulty adapting to the White, middle-class culture of science (Carlone & Johnson 2007; Chang et al. 2011, 2014). The hurdles—both structural and social-psychological—to young URM scholars' full integration into the scientific community (Graham et al. 2013, Tinto 1987) have negative effects on their academic confidence, engagement, and likelihood of persisting in STEM (Carlone & Johnson 2007, Chang et al. 2014).

The second explanation attributes these racial gaps to URM students' lower levels of academic preparation at the K-12 level, which limits their attainment of both general and STEM education at the undergraduate and postgraduate levels. Differences in K-12 mathematics achievement may be especially consequential, as research has shown this to be one of the single best predictors of success in college (Adelman 2006). After controlling for these disparities in precollege academic performance, studies indicate that URMs are actually more likely than Whites to (*a*) enroll in college (Ross et al. 2012) and (*b*) declare a STEM major (Riegle-Crumb & King 2012). Furthermore, conditional on degree attainment, it appears that URMs choose fields of study, including STEM, at rates similar to those of Whites (NSB 2014, Xie & Killewald 2012). Identifying the causes of the racial preparation gap is therefore key to understanding racial gaps in both general education and STEM education at the undergraduate and postgraduate levels.

The most controversial explanation for racial disparities in academic performance focuses on genetic or otherwise innate differences in cognitive abilities such as general intelligence (e.g., Herrnstein & Murray 1994) or spatial thinking (e.g., Lynn 1996). Such explanations are generally met with skepticism, criticized as lacking empirical support and reflecting racist ideologies (e.g., Fischer et al. 1996), and rejected as implausible explanations for racial/ethnic gaps in STEM achievement and participation.

Sociological explanations for the racial preparation gap focus on the structural causes of racial inequalities in access to the resources and opportunities that are more directly linked to STEM educational outcomes. Most often these explanations focus on two forms of structural inequality: social class differences that are closely correlated with race/ethnicity and school quality differences that are closely related to both race/ethnicity and social class. URM students are significantly overrepresented among relatively poor, less educated, underemployed families and families headed by single parents compared with White and Asian students (Kao & Thompson 2003). Black, Hispanic, and Native American youth are therefore less likely to be supported by financial and parental resources. The findings of numerous studies support this hypothesis by showing that, after controlling for family SES, a large portion (but not all) of the racial achievement gap in math and science is eliminated (Downey 2008, Hattie 2008, Jencks & Phillips 1998, Kao & Thompson 2003).

Racial/ethnic segregation of schools at the primary and secondary levels has significant implications because it concentrates URM students in poorly funded, underperforming, and understaffed schools (Condron & Roscigno 2003, Goldring et al. 2013, Logan et al. 2012). Higher representation of URM students is associated with multiple disadvantages, including fewer qualified teachers (Clotfelter et al. 2005, Goldring et al. 2013, NSB 2014), fewer advanced courses (Ross et al. 2012, Wang 2013), larger class sizes (Ross et al. 2012), and outdated learning materials (Oakes & Saunders 2004). The effect of these class-based disparities is compounded by racial/ethnic disparities within schools: URM students are more likely to be placed in low-track courses and their teachers tend to have low expectations for their learning (Tenenbaum & Ruck 2007). The combined effects of the class- and race-based disparities lead URM students to have higher rates of attrition from, as well as poorer performance in, the educational pipeline than White and Asian students (Oakes 1990, Ross et al. 2012).

We encourage researchers to seriously engage with both the structural and the social-psychological explanations and to integrate both perspectives to achieve a more comprehensive understanding of racial disparities in STEM. To uncover the underlying causes of the observed racial differences in STEM education, a life course perspective is required to identify how racial gaps emerge in early childhood, grow along the educational ladder, and likely result from an accumulation of social advantage and disadvantage. Finally, better research is also needed to separate the effects of race from those of family SES, as the two are highly correlated in US society.

CONCLUSION

STEM education is a complicated social phenomenon. A vast literature now exists on the state of STEM education, though a small part of the larger sociology of education literature addresses STEM directly. We have distinguished research focusing on two key components of STEM education: attainment of education in general and attainment of STEM education conditional on attainment of general education. In this concluding section we offer a few summary observations on the strengths and weaknesses of this literature.

First, the current literature is strong on the social determinants of general education and weak on the social determinants of STEM education conditional on general education. This is because research in sociology is concerned mostly with social inequality in attaining general education rather than STEM or any particular type of education. Second, more research is needed to explain the STEM achievement gap between the United States and other high-performing countries. Because education is an important social institution whose success depends on many broad factors beyond schools, such as family, labor market structure, culture, and international context, any attempt to find a single root cause for the perceived underachievement of American students would be too simplistic. Sociology has had a long tradition of studying the influences of macro-level forces, such as social institutions, social context, and culture, on individuals' outcomes and is thus uniquely situated to make important contributions toward understanding the STEM achievement gap between the United States and other countries. Third, although a great deal of research has studied the underachievement of certain racial/ethnic groups and women in STEM education, little attention has been paid to the reverse side of the issue: the determinants of the success of certain individuals and social groups in STEM education. We hope that researchers will fill these gaps in the future.

Research on STEM education is multidisciplinary, but there is little integration across the many disciplinary streams of research on STEM education. Sociologists can and should learn from research in other fields on the topic. We have highlighted the important role that social-psychological attributes appear to play in students' success in STEM education. This is an area from which sociologists have learned a great deal and will continue to learn. What are the economic returns to STEM education (i.e., not necessarily STEM degrees) broadly defined? Are students driven to acquire STEM education for its monetary returns or out of intellectual curiosity? To answer these questions, sociologists can learn from economists. Finally, sociological research on STEM education will benefit from a better understanding of how science and math classes are taught in schools at different levels. For this, sociology can learn from the large literature in education research. While intersecting with research from other fields, sociological research on the study of STEM education has already made important contributions to the field. However, it should be further expanded and improved, as concerns regarding the national competitiveness of the United States continue to be raised and discussed in the future. There are too many questions to which the current literature offers no satisfactory answers.

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