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(Review Article)

Social skills for students diagnosed with autism spectrum disorders in STEM education

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Abstract

Students diagnosed with autism spectrum disorders (ASD) are showing high levels of interest in STEM fields. This paper will review the diversity of thought among individuals with special needs from a research perspective, efforts are made to identify possible sets of skills or common characteristics among individuals either with Autism Spectrum Disorder (ASD) and related learning differences, such as specific learning disabilities, or with mental health disorders that affect learning (emotional disturbance), as well as other health-related disorders (e.g., Attention Deficit Hyperactivity Disorder – ADHD). This paper presents the theoretical framework and the factors influencing for the Selection of University STEM Programs among Students with Autism Spectrum Disorder. To this end, researchers have attempted to develop an assessment process and measure the impact of an educational model on outcomes related to STEM. Educators and employers are working together to promote students diagnosed with autism by developing skills related to the STEM fields. Efforts are finally made to encourage a blend of evidence-based instructional methods in order to support the act of including of students diagnosed with ASD.

Keywords: Autism Spectrum Disorders; STEM Education; Social Skills; Digital Technologies; Rehabilitation

1. Introduction

Autism is officially categorized as a neurodevelopmental disability under autism spectrum disorders (ASD) in the latest edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM) (American Psychiatric Association, 2013). The globalization of the economy and the continuous advancement of technology necessitate that the skills and knowledge required for a specific job are constantly evolving. The demand for labor in the STEM fields increased by 175% between 1980 and 2008, compared to a 40% increase in the overall U.S. workforce (Carnevale, Smith, and Mellon, 2011). It was estimated that there will be 2.4 million unfilled job openings in STEM fields between 2008 and 2018. However, the U.S. education system is not producing enough individuals with STEM competencies to fill these positions (Carnevale et al., 2011). As the U.S. seeks to promote a "globally competitive high-level scientific and engineering workforce" in order to remain a leader in a technologically advanced global economy (Nagle, Marder, and Schiller, 2009), individuals with autism spectrum disorder appear to have the potential to play a significant role in achieving this important societal goal. Recent studies suggest that the prevalence of autism is increasing in the United States, with current estimates indicating that 1 in 50 children is diagnosed with autism spectrum disorder (Blumberg, Bramlett, Kogan, Schieve, Jones, and Lu, 2013). A greater increase is observed in the higher-functioning end of the broad spectrum of intellectual expressiveness (Keyes et al., 2012), namely among youth with high-functioning autism who are more capable of pursuing their interests in STEM through postsecondary education.

Studies have focused on how the characteristics of individuals with autism spectrum disorder predict their professional and occupational activities after completing school. The term "21st-century skills" holds various meanings across

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different professions, and the descriptions of these terms are not consistent throughout the literature. There are also significant challenges in assessing outcomes related to these skills, as they cannot be easily measured using traditional academic assessments.

Soland et al. (2013) identify and categorize a wide range of competencies/skills and related assessment approaches that reflect vital skills required now and in the future. They describe broad categories defined by the National Research Council and related organizations with expertise in these competencies. The broad categories include: (a) Cognitive competencies, (b) Interpersonal competencies, and (c) Intrapersonal competencies.

The cognitive category typically includes knowledge of critical academic content across disciplines and may also involve critical thinking and creativity. The interpersonal category includes the skills students need to connect and relate with others. These competencies require a foundation of basic communication and collaboration. The intrapersonal category involves abilities related to an individual's attitudes and behaviors that affect their ability to solve problems in everyday life across various settings (e.g., school, work, community).

In conclusion, we stress the importance of all digital technologies in the field of education and in Autistic's training. These technologies are highly effective and productive and facilitate and improve assessment, intervention, and educational procedures through mobile devices that bring educational activities anywhere [53-56], various ICTs applications that are the main supporters of education [57-63], and AI, STEM, GAMES and ROBOTICS [64-69], that raise educational procedures to new performance levs. Furthermore, the development and integration of ICTs with theories and models of metacognition, mindfulness, meditation, and the development of emotional intelligence [70–86], accelerates and improves educational practices and results more than those, particularly in Autistic's training and treating domain and its practices like assessment and intervention.

2. Theoretical Framework for the Selection of University STEM Programs among Students with Autism Spectrum Disorder

There is increasing evidence indicating a higher enrollment in the fields of Science, Technology, Engineering, and Mathematics (STEM) among individuals with autism spectrum disorder. Baron-Cohen, Wheelwright, Burtenshaw, and Hobson (2007) studied a sample of university students in the United Kingdom and demonstrated a higher enrollment of individuals on the autism spectrum among mathematics students compared to students in medicine, law, or social sciences. Wei, Yu, Shattuck, McCracken, and Blackorby (2012) analyzed a national sample of students in special education in the United States and found that students with autism spectrum disorder had the highest rates of participation in STEM (34%) among 11 categories of disability and students in the general population.

The empirical evidence aligns with the Empathizing–Systemizing (E-S) Theory, which suggests that individuals with autism spectrum disorder may have an inherent tendency to gravitate toward STEM fields (Baron-Cohen et al., 2007; Baron-Cohen, 2009). The Empathizing–Systemizing (E-S) Theory indicates that individuals on the autism spectrum tend to have a proportionally greater inclination toward systemizing compared to emotional empathy. "Systemizing" refers to the analysis or construction of rule-based systems to explain the world around them, whereas "empathizing" refers to social and emotional reactions to the thoughts and feelings of others (Baron-Cohen, 2006; 2009). The E-S theory suggests that individuals with autism spectrum disorder are average or above average in systemizing, but below average in emotional empathy (Baron-Cohen, 2009). Systemizing often requires thinking or skills needed to analyze and build systems, which are also crucial for succeeding in many STEM-related fields (Baron-Cohen et al., 2007).

Primarily derived from Bandura's (1986) general Social Cognitive Theory, the Social Cognitive Career Theory (SCCT, its international acronym) (Lent, Brown, and Hackett, 1994) uses a unified approach to understanding the interaction between individual, environmental, and behavioral variables in academic and career choice. Career development is achieved by focusing on three key principles: self-efficacy, outcome expectations, and goals (Lent et al., 1994). Key factors influencing individuals with disabilities in choosing careers in science and technology fields include individual motivation and personal determination, family support and advocacy, as well as positive learning and educational experiences in STEM fields (Alston and Hampton, 2000; Lindstrom and Benz, 2011; Mastropieri and Scruggs, 1992; Wang, 2013). The Social Cognitive Career Theory highlights the role of environmental factors in either reinforcing or weakening one's career behavior (Lent et al., 1994). Although the Social Cognitive Career Theory helps explain career choice and development among youth in the general population, very few studies have applied this theoretical framework to understand career development among youth with autism spectrum disorder.

In the following study, Wei, Yu, Shattuck, and Blackorby (2017) examine the association between STEM preparation factors during the later school years and undergraduate/graduate education in STEM subjects, using a large, nationally representative sample of students with autism spectrum disorder in the United States. The study applied the Social Cognitive Career Theory (SCCT) framework to explore how STEM learning experiences and individual characteristics jointly contribute to undergraduate/graduate-level STEM participation.

Below, the study by Wei, Yu, Shattuck, and Blackorby (2017) explores the relationship between STEM preparation factors during the final years of schooling and undergraduate/graduate education in STEM fields, using a large, nationally representative sample of students with autism spectrum disorder in the United States. They applied the framework of the Social Cognitive Career Theory (SCCT) -to examine how STEM learning experiences and individual characteristics jointly contribute to undergraduate/graduate selection in STEM fields.

3. Factors Influencing the Choice of STEM University Programs Among Students with Autism Spectrum Disorder

Utilizing a rich, nationally representative longitudinal dataset of students on the autism spectrum, the study by Wei, Yu, Shattuck, and Blackorby (2017) reveals the first national picture of how high school preparation factors and individual characteristics are associated with students' entry into STEM majors. The findings remain well-aligned with the Social Cognitive Career Theory (SCCT), which posits that an individual's intention to engage in a specific activity is influenced by environmental factors (such as exposure to advanced math courses) and individual factors (such as conversational ability and race/ethnicity).

There is a range of school-related factors that are particularly effective in supporting the transition of students through the STEM pipeline from high school to college-level STEM degree programs. Key factors identified in the literature (Chiang, Cheung, Hickson, Xiang, and Tsai, 2011; Roberts, 2010; Stodden and Mrozek, 2010; Wang, 2013) include the following

3.1. Academic Performance

Academic performance in high school subjects, including standardized test scores in mathematics and science, is linked to the continuation of academic studies in STEM fields (Bonous-Hammarth, 2000; Sahin, Morgan, and Erdogan, 2012). Performance on standardized tests and overall high school GPA appear to play an important role in pursuing STEM degrees at the university level among students in the general population.

3.2. The Rich Set of High School Experience Variables

High school preparation in mathematics and science courses is considered one of the strongest predictors of selecting a STEM major (Tai, Liu, Maltese, and Fan, 2006; Wai, Lubinski, Benbow, and Steiger, 2010; Wang, 2013). According to the findings of Wei, Yu, Shattuck, and Blackorby (2017), the difference among students on the autism spectrum who take advanced mathematics courses in high school is striking (42% among those with a STEM major versus 22% among those with a non-STEM major). Based on Wang's findings, the critical role of attending advanced mathematics and science courses in an inclusive, high-level high school environment is emphasized for the development of students' intentions to choose a STEM major in college and university education.

3.3. Individual Characteristics

3.3.1. Communication Skills

Communication ability is an important factor significantly associated with enrollment in college majors related to STEM. Communication skills also have the potential to be improved through effective educational interventions and supports. Related studies have shown that the lack of communication skills in young adults on the autism spectrum can limit their ability to understand and use the rules of social behavior, resulting in greater difficulties during the transition from high school to college in maintaining the mutual interactions necessary for college learning.

Although speech/communication therapy is the most common special education service provided to students with autism spectrum disorder, the lack of information about these supports and services, as well as their unavailability, have been highlighted as major barriers. Moreover, the provision of speech/communication services after high school did not meet the recognized need for pursuing STEM studies (Wei, Wagner, Hudson, Yu, and Shattuck, 2014). According to the study by Wei, Yu, Shattuck, and Blackorby (2017), 23.3% of students with autism spectrum disorder indicated a need for speech/communication services after high school, but only 13.6% had received such services up to six years after graduation. These findings add valuable information to the literature, highlighting the importance of communication skills for students with autism spectrum disorder entering STEM degree programs. At the same time, they suggest that providing greater support for communication skills is crucial and essential for students with autism spectrum disorder in order to enter and succeed in the STEM fields.

3.3.2. Teamwork/Collaboration Skills

The ability to participate in teamwork and collaboration is also considered important. Like communication, collaboration is often defined as a set of skills rather than a single skill. Collaboration is often viewed as a form of communication that involves abilities related to conflict resolution and negotiation (Pellegrino and Hilton, 2012; Lai et al., 2017).

3.3.3. Sociodemographic Differences

Sociodemographic differences are considered particularly important in STEM-related research (Crisp et al., 2009; Wang, 2013). The continued underrepresentation in STEM participation based on gender, race, and disability status remains a significant issue requiring further research (National Science Foundation, 2013; Wang, 2013; Zhang et al., 2004). The study by Wei, Yu, Shattuck, and Blackorby (2017) highlighted a significant racial/ethnic gap in STEM major enrollment among young adults with autism spectrum disorder. White students were six times more likely to enroll in STEM-related majors compared to minority students. In contrast, a report from the National Science Foundation (2013) showed no racial gap in the intention to enroll in STEM-related majors among the general population, with 37% of White, 37% of Black, 41% of Hispanic, 49% of Asian, and 28% of Native American students expressing their intention to pursue STEM-related majors.

4. Social–Environmental Determinants in STEM Education

4.1. Related Factors and STEM Education

Social and institutional environments matter for STEM educational outcomes. Although there is evidence that the social level of the broader environment, such as the neighborhood, affects children's cognitive ability (Brooks-Gunn et al., 1993; Sharkey and Elert, 2011), their verbal skills (Sampson et al., 2008), and their school graduation rates (Harding, 2003), little is known about other potential related factors, such as the characteristics of the local labor market or proximity to science-focused industries.

Schools vary widely in their STEM education resources, such as the quality of teachers and science laboratories, reflecting largely inter-school inequalities tied to the students' family economic status. Studies of primary and secondary education suggest that funding and resource availability shape the extent to which students engage and excel in STEM education (Oakes, 1990; Museums et al., 2011; Wang, 2013). The structural impact of resources appears crucial: well-resourced schools offer a relatively wide range of mathematics and science courses and greater access to resources such as textbooks and scientific laboratory equipment (Oakes and Saunders, 2004). In contrast, the impact of school resources on learning cultures or the promotion of STEM education has received much less attention (Wang, 2013; Lewie and DiPrete, 2014).

School resources are also positively associated with the staffing of high-quality teachers (Clotfelter et al., 2005). Numerous studies show that access to trained and experienced mathematics and science teachers positively affects both students' learning (Darling-Hammond, 1999; Wayne and Youngs, 2003; Hill et al., 2005; Hattie, 2008; Sadler et al., 2013) and their interest and passion for science (Woolnough, 1994; Osborne, 2003; Maltese and Tai, 2011; Tytler and Osborne, 2012; Sjaastad, 2012).

In higher education, research indicates that institutional characteristics and climate influence students' pursuit and persistence in a STEM major (Seymour and Hewitt, 1997; Museums et al., 2011; Hurtado and Carter, 1997; Seymour and Hewitt, 1997; Chang et al., 2014). In academic environments where students receive engaging instruction, encouragement from faculty and peers, sufficient financial aid, and networking opportunities, positive links are found with STEM engagement and persistence (Graham et al., 2013; Chang et al., 2011). Conversely, unsupportive university environments, highly competitive classrooms, poor teaching quality, and excessive workloads are negatively associated and can reduce STEM academic engagement, achievement, and persistence (Seymour and Hewitt, 1997; Cabrera et al., 1999; Carlone and Johnson, 2007).As a result of these negative factors, otherwise capable students may be pushed toward non-STEM majors (Carlone and Johnson, 2007; Chang et al., 2011) or even leave higher education altogether (Hurtado and Carter, 1997). Especially effective are opportunities for collaboration with faculty on undergraduate research projects, aimed at building student confidence and identification with the scientific community (Grandy, 1998; Chang et al., 2011; Graham et al., 2013).

4.2. Family Factors and STEM Education

Family factors, especially the family's socioeconomic status (SES), are closely linked to students' performance and interest in higher education STEM fields and the attainment of STEM degrees. Recent reports and studies confirm the relationship between family socioeconomic status and interest in as well as employment prospects in STEM fields. A prominent explanation attributes this to the fact that families of middle and high socioeconomic status are able to provide their children with encouragement, support, exposure to science, and access to STEM enric*hment experiences that are crucial for the development and maintenance of early interest, confidence, and aspirations in STEM (Turner et al., 2004; Mackiewicz et al.,2012).

While there is clear empirical evidence that family socioeconomic background influences STEM engagement and achievement early in life, it is unclear how far into the educational and/or career pathway these effects extend. Analyses of studies suggest that family socioeconomic background continues to exert significant influence well beyond elementary and secondary school. In fact, students from high socioeconomic backgrounds constitute a disproportionate percentage of those who obtain STEM degrees and pursue STEM careers (Ware and Lee, 1988; Chen, 2009).

4.3. Individual Factors and STEM Education

Individual cognitive ability, spatial ability, numerical ability, and other indicators of fundamental cognitive functions (Selke, 2005) are closely associated with performance in mathematics and the natural sciences in both compulsory and undergraduate education. However, spatial and quantitative abilities are considered uniquely essential prerequisites for achievement in STEM fields (Selke, 2005; Reilly and Neumann, 2013), and spatial thinking is regarded as a significant determinant of success in STEM education, being linked to interest and confidence in mathematics and science (Wai et al., 2010).

Researchers now specifically recognize certain individual social-psychological characteristics that are closely related to engagement and success in STEM education (Tai et al., 2006; Maltese and Tai, 2011; Wang, 2013). These include self-perception in mathematics and science, interest in science, and aspirations for a science-related career.

An individual's perception of science, or beliefs about their abilities in mathematics and science, predicts participation in advanced STEM courses, the pursuit and persistence in STEM fields, the attainment of STEM degrees, and entry into STEM careers (Correll, 2001; Mau, 2003; Maltese and Tai, 2011; Wang, 2013). Specifically, aspiring for a scientific career appears to be a prerequisite for earning a STEM degree (Xie and Shouman, 2003; Tai et al., 2006), and a loss of interest is a primary reason for attrition from STEM majors (Seymour and Hewitt, 1997).

Recently, researchers have defined the concept of "science identity," meaning the sense that science is "right" for an individual (Cech et al., 2011; Archer et al., 2012; Perez et al., 2014). Science identity is thought to form early and to influence engagement with STEM education and careers throughout life (Cech et al., 2011; Simpkins et al., 2006; Perez et al., 2014).

4.4. Biological Sex and STEM Education

Despite significant progress toward gender equality, gender disparities continue to be a defining feature of STEM education. Gender gaps dominate the perception of gender and STEM and are often cited as evidence of the innate superiority of men in STEM education (Correll, 2001; Nosek et al., 2002; Hyde, 2005).

Early studies of standardized test performance also showed gender parity or a slight female advantage in basic computation and understanding of mathematical concepts across all grades (Hyde et al., 1990; Hedges and Nowell, 1995). Studies document the advantages of women (as well as men) in specific tasks related to spatial abilities (Hyde, 2005; Spelke, 2005; Halpern et al., 2007). However, relevant analyses challenge the view that the observed gender differences in STEM achievement are immutable and socially significant. The social significance of the documented gender disparities in STEM achievement remains unclear (Xie and Shouman, 2003; Weinberger, 2005) and further investigation is needed.

Currently, the increase in women's participation in STEM fields has been driven mainly by the overall rise in women's educational participation (Mann and DiPrete, 2013), especially regarding persistence in the "science pipeline" during college and graduate education (Miller and Wai, 2015). Thus, while the number of women earning undergraduate and graduate degrees in STEM fields has steadily increased, the proportional representation of women in many STEM disciplines has not increased since the 1980s (England and Li, 2006; England et al., 2007; DiPrete and Buchmann, 2013; Mann and DiPrete, 2013) and may even be declining in some engineering fields (Mann and DiPrete, 2013). Women in the U.S. and other industrialized countries have earned most degrees in biological and social sciences since the 1980s but remain significantly underrepresented among degree recipients in engineering, physical sciences, mathematics, and computer science (Charles and Bradley, 2002, 2006, 2009; Xie and Shauman, 2003; Xie and Killewald, 2012; DiPrete and Buchmann, 2013).

The perception that men are inherently more talented and interested in science is a widespread cultural stereotype (Nosek et al., 2009; Leslie et al., 2015), and although most people consciously reject this notion (Hyde et al., 1990), implicit association studies confirm the pervasive presence of the "math = male" stereotype across age, race/ethnicity, gender, and country (Nosek et al., 2002; Kiefer and Sekaquaptewa, 2007; Nosek et al., 2009; Cvencek et al., 2011). Reflecting this normative belief, girls consistently report lower self-assessments of quantitative skills, lower confidence in their mathematical abilities, less interest and lower motivation for learning mathematics and science, and higher levels of math anxiety compared to their male peers. They also show less interest in pursuing STEM careers, even when controlling for achievement (Correll, 2001, 2004; Fredricks and Eccles, 2002; Watt, 2004, 2006; Jacobs et al., 2006; Else-Quest et al., 2011; Sadler et al., 2012; Wang et al., 2013). Girls are also more likely than boys to express an interest in pursuing people-oriented careers, to view science as inconsistent with this orientation, and to perceive the scientific lifestyle as unattractive (Miller et al., 2006).

Essentialist explanations for women's career choices argue that they are a natural outcome of biologically based sexual predispositions. A prominent theory suggests that prenatal hormonal exposure predisposes females toward a natural affinity for human interaction and caregiving relationships and males toward an innate interest in inanimate, technical, and mechanical objects (Baron-Cohen, 2003; Su et al., 2009; Schmidt, 2011). Another theory posits that the interest gap is linked to women's biological predisposition for childbearing, leading them to prioritize family over work roles (Ceci et al., 2009; Ceci and Williams, 2010, 2011).

Recent studies do not support these essentialist explanations. Research indicates that interest in STEM fields is largely responsive to environmental influences (Cheryan et al., 2009, 2011; Murphy et al., 2007; Stout et al., 2011). Socio-psychological and socio-cultural perspectives offer more nuanced explanations for the gender interest gap. Studies show that macro-level cultural conditions influence gender differences in STEM interest through various causal mechanisms, which are encoded and transmitted via the attitudes and expectations of parents, teachers, and other significant individuals.

4.5. Racial Differences in STEM Education

Underrepresented minorities have made significant progress in closing the racial gap with Whites and Asians, but substantial disparities still persist (Nord et al., 2011). Despite the substantial participation of underrepresented minorities (URM) — African Americans, Hispanics, Native Americans, and others — in STEM education, they continue to be underrepresented and lag behind Whites and Asians (Chen and Soldner, 2014).

Recent studies show that the disadvantage for underrepresented minorities is more pronounced, both in magnitude and in the degree of divergence, among high-achieving students (Hedges and Nowell, 1999; Neal, 2005; Reardon, 2008; Riegle-Crumb and Grodsky, 2010). Reardon (2008) found that among elementary school students, the Black-White achievement gap in mathematics grew twice as fast among high-achieving students as it did among low-achieving students.

The number of underrepresented minorities entering college and earning STEM degrees has been steadily increasing over time. Notably, the percentage of underrepresented minorities holding any science and engineering degree rose from 17% in 2000 to 20% in 2011 (NSB, 2014).

The effects of racial/ethnic differences on institutional integration are not well understood, but because elite graduate programs and industries disproportionately draw from top elite universities, these differences may have significant implications for stratification within graduate schools and the workforce. While interest in STEM is higher among Asians (Xie and Goyette, 2003; DeWitt et al., 2011), studies at all education levels show that underrepresented minorities express the same level of enthusiasm for STEM education and careers as their White peers, despite lower early achievement levels (Rigle-Crumb et al., 2011; Riegle-Crumb and King, 2010; NSB, 2014).

Racial disparities in STEM education have been attributed either to lower levels of interest in science among underrepresented minority students or to socio-psychological factors that may limit the extent to which these students can translate their interests into meaningful STEM engagement. Studies reveal that URM students in STEM majors often struggle with feelings of isolation (Seymour and Hewitt, 1997) and find it difficult to adapt to the White, middle-class culture of science (Carlone and Johnson, 2007; Chang et al., 2011, 2014).

The most controversial explanation for racial disparities focuses on genetic or otherwise innate differences in cognitive abilities such as general intelligence (Herrnstein and Murray, 1994) or spatial reasoning (Lynn, 1996). Such explanations are generally met with skepticism, criticized for lacking empirical support, and viewed as reflecting racist ideologies (Fischer et al., 1996). They are largely dismissed as unlikely 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 resources and opportunities that are more directly connected to STEM educational outcomes (Downey, 2008; Hattie, 2008).

5. Connecting High School Experiences and Enrollment in University STEM Programs Among Students with Autism Spectrum Disorder

Studies that have investigated participation in undergraduate or graduate programs among students with autism spectrum disorder (ASD) have found that high school experiences play a significant role in the successful enrollment and participation of students in undergraduate/graduate education programs. There are also several studies that have examined the background of advanced, high-level science and mathematics classes and their impact on college students' STEM career choices.

A study by Tyson, Lee, Borman, and Hanson (2007) explored how the selection of science and mathematics courses in high school predicted the attainment of a STEM degree among college graduates. It was found that students who took high-level science courses (such as Chemistry and Physics) or successfully completed Accounting in high school were more likely to earn a STEM degree from a public university compared to students who did not complete these respective courses.

Another study by Robinson (2003) also examined the background of advanced science and mathematics courses in the Advanced Placement Program and their impact on college students' STEM career choices. The analysis showed that the likelihood of pursuing a STEM career — such as engineering, natural sciences, mathematics, and the medical field — was significantly associated with taking Accounting and advanced science courses. The results also confirmed that both minority and non-minority students who took Accounting and/or science courses in high school were more likely to choose STEM careers over other career paths. Similar findings have been confirmed by a number of studies focused on minority students (Crisp, Nora, and Taggart, 2009; Simpson, 2001).

Grades in mathematics and science during high school have been considered among the strongest predictors of participation in STEM courses in college, in studies focusing on the general student population (Bonous-Hammarth, 2000; Crisp et al., 2009; Porter and Umbach, 2006; Sahin et al., 2012). However, a recent study by Wang (2013) suggests that exposure to mathematics and science courses has a stronger effect than performance when it comes to entering STEM fields. Two studies on mechanical engineering students showed that continuation into an undergraduate or graduate engineering program was positively associated with previous academic achievements (French, Immekus, and Oakes, 2005; Zhang, Anderson, Ohland, and Thorndyke, 2004).

The study by Wei, Yu, Shattuck, and Blackorby (2017) explores the correlation between STEM preparation factors during the final school years and participation in undergraduate STEM education, using a large, nationally representative sample of students with autism spectrum disorder in the United States. Among students with different types of disabilities, including ASD, physical inclusion in mainstream schools and participation in general education classes appear to increase the likelihood of their enrollment in undergraduate/graduate programs (Baer, Flexer, Beck, Amstutz, Hoffman, Brothers, et al., 2003; Test, Mazzotti, Mustian, Fowler, Kortering, and Kohler, 2009). Recent research has shown that inclusion of students with disabilities in the general education setting is associated with higher socio-behavioral and academic outcomes (Hunt and McDonnell, 2007; McCurdy and Cole, 2013).

However, further studies are needed to promote understanding of the best ways to include students with disabilities in advanced courses (including mathematics, accounting, and science courses), taking into account the type and diversity of cognitive and behavioral functioning within this group. Research that distinguishes effective strategies for encouraging the inclusion of students with disabilities at different levels would be welcomed by the educational community (Harrower and Dunlap, 2001). Also, recognizing the compounded racial inequalities that exist among ethnic minorities with disabilities would be an important first step toward providing appropriate services aimed at fostering and encouraging interest in STEM within this population group.

6. Employment and Postsecondary Educational Activities for Young Adults with Autism Spectrum Disorders during the Transition to Adulthood

Several studies have explored the educational and employment activities of young adults with autism spectrum disorders (ASD) who have completed secondary education. Analyses revealed low rates of community employment, with the majority of young adults (56%) spending time in sheltered workshops or day activity centers. Interestingly, young adults with ASD without intellectual disability were three times more likely to have no daytime activities compared to adults with ASD who had intellectual disabilities. Differences were also observed in behavioral functioning across different employment/day activity groups. The findings suggest that the current service system is inadequate in meeting the needs of young people with ASD without intellectual disabilities during their transition to adulthood.

Researchers have examined behavioral correlates of a related composite measure, social functioning, which integrates independence in employment activities, living arrangements, and friendships (Howlin et al., 2004). The most consistent correlation is with IQ, as individuals with ASD and comorbid intellectual disability exhibit lower optimal social functioning (reflecting less independence) compared to individuals with ASD and higher IQ levels (Eaves and Ho, 2008; Farley et al., 2009; Gillberg and Steffenburg, 1987; Howlin et al., 2004; Lord and Bailey, 2002).

A study by Lounds and Mailick (2011) investigated the diversity of adult activities for children diagnosed with ASD in the early 1990s, a period marked by a rapid increase in ASD diagnoses (Gurney et al., 2003). They found low employment rates during the transition to adulthood, a finding consistent with earlier studies covering a broader age range (Ballaban-Gil et al., 1996). It was also found that those employed tended to have modest jobs, and none of the individuals in the sample were employed full-time. Similar findings are observed in the studies by Ballaban-Gil et al. (1996), Howlin et al. (2004), and Eaves and Ho (2008).

The study by Lounds and Mailick (2011) examined the relationships between functional independence, comorbid psychiatric disorders, and social functionality among adults with ASD. It was found that among adults aged 22–53 with ASD, reduced independence in daily living activities and receiving psychological/psychiatric services (indicative of a comorbid psychiatric diagnosis) were associated with lower social functioning and less independence in adulthood (Esbensen et al., 2010). These findings are consistent with the study by Farley et al. (2009), which found that adults with ASD and higher adaptive behaviors had more independent social functioning compared to those with lower adaptive behaviors.

Particular concern was raised by the finding that young adults had few or no formal daytime activities following the completion of school and educational programs. Nearly 25% of those with ASD without comorbid psychiatric disorders, as well as those without ASD, were three times more likely to have no daily activities compared to those with ASD and comorbid psychiatric disorders. This divergent pattern likely does not reflect a lack of capability among young people with ASD but rather the inadequacy of the current service system in meeting the needs of young adults with ASD without comorbidities as they transition to adulthood. In fact, only 18% of young adults without comorbidities were receiving some type of employment or vocational service (e.g., supported employment, sheltered workshop), compared to 86% of young adults with comorbid intellectual disabilities.

Significant differences were found in the behavioral functioning of the group of young adults who had no daytime activities. Regarding functional independence, those without daily activities had greater functional independence than those receiving day services, but less functional independence compared to those participating in an adult educational program. The same pattern appeared for autism symptoms and maladaptive behaviors. Those without daytime activities exhibited symptoms and behaviors that appeared less severe than those receiving adult day services but more severe compared to those engaged in employment or specialized employment services.

The percentage of young adults without daytime activities who had a comorbid psychiatric diagnosis was extremely high (86%). Although differences in the rate of comorbid psychiatric diagnoses by employment/day activity group were not statistically significant, this factor likely served as a barrier to pursuing postsecondary or graduate education among young adults with ASD. Future efforts should focus on increasing the rate of employment/daytime activity among young adults with ASD, and future research should aim to record outcomes with greater statistical power.

Nearly 50% of young adults with ASD without psychiatric comorbidities were pursuing a bachelor's or postsecondary education degree. Although this rate is significantly lower compared to their typically developing peers, it suggests that pursuing a postsecondary degree is a viable option for many young adults with ASD without psychiatric comorbidities. Future research should focus on whether these young adults eventually obtain a degree and whether this degree translates into a sustainable career over time.

7. Link Between Autism and Career Intentions

Autism and elevated levels of autistic traits may be associated with specific profiles of strengths and weaknesses, which could play a significant role in employment and career choices. Autistic individuals are more prominently represented in Science, Technology, Engineering, and Mathematics (STEM) fields than in non-STEM careers such as business, retail, or publishing (Ruzich, Allison, Chakrabarti, et al., 2015; Wei et al., 2013). Additionally, fathers and grandfathers of autistic children are more likely to have worked in engineering (Baron-Cohen et al., 1997). Geographic regions associated with employment in information technology also show increased rates of autism (Roelf Sema et al., 2012).

In the general population, students who study natural sciences show higher autistic traits than those studying non-scientific disciplines (Baron-Cohen et al., 2001; Hoekstra et al., 2008; Pisula et al., 2013; Wakabayashi et al., 2006), and those studying physical sciences and mathematics tend to score higher than students in biological sciences or health-related fields (Austin, 2005; Baron-Cohen et al., 2001; Wakabayashi et al., 2006). However, while research findings suggest a link between autistic traits and scientific study or employment, the nature of the relationship remains unclear. It could be the result of a preference for systemizing or a desire for reduced social interaction—both of which may be characteristics of individuals pursuing scientific fields (Morsanyi et al., 2012). Nevertheless, a correlation between autistic traits and STEM subjects may be important in explaining why males are more prominently represented in these fields than females.

8. Connection between Autism and Engineering

8.1. Autistic Traits, STEM and Engineering

Autism is a serious disorder affecting the normal development of social relationships, communication, and imagination (APA, 1994). There is considerable evidence suggesting it is due to neuropathology (Bauman and Kemper, 1994), and family and twin studies indicate that it has a genetic basis (Bailey et al., 1995; Bolton and Rutter, 1990; Folstein and Rutter, 1977; Folstein and Rutter, 1988). Its incidence was approximately 1 in 1000 (Baron-Cohen et al., 1996; Gillberg, Steffenberg and Schaumann, 1991), although this rate has increased significantly in recent years. Nevertheless, the genetic theory of autism leads to the causal hypothesis that autism may not occur randomly, but certain types of parents may have a higher risk of having a child with autism.

In a particularly large study, researchers examined the possible link between autism and the professions of parents. The hypothesis investigated whether engineers might be overrepresented among the parents and grandparents of children with autism or Asperger syndrome. Cognitively, children with autism display deficits in the development of "folk psychology," while they exhibit normal or even higher levels of development in "folk physics."

- The theory of Domain Specificity suggests that there may be at least four common "core knowledge areas" (Carey, 1985; Gelman and Hirschfield, 1994; Pinker, in press; Wellman and Gelman, in press). These core areas are:
- Folk biology, which is our common ability to classify the natural world and allows the rapid categorization of individual plants (e.g., as edible or non-edible) or animals (e.g., as predators or prey).
- Folk physics, which is our common ability to understand physical objects based on their causal/mechanical properties and enables the flexible use of tools.
- Folk psychology, which is our common ability to understand the behavior of other people based on their intentions, allowing quick interpretation and prediction of their actions as well as social influence.
- Folk mathematics, which is our common ability to count and estimate the probability of events, facilitating the estimation of numbers and probabilities.

These core knowledge areas appear to be innate in their "initial state" (in the sense that they develop in the majority of humans) and form a kind of "folk science" because they are used explanatorily by humans, regardless of culture. They are considered "domain-specific," appearing to develop relatively independently of each other, resulting in variations in the rate of development across individuals. These four knowledge areas likely played a significant role in the evolution of the human brain. In other words, possessing each cognitive area would have enhanced an individual's adaptability in different ways.

Autism is considered an interference with folk psychology combined with an enhancement in folk physics. Folk psychology and folk physics are especially interesting because they both involve causal reasoning. Generally, folk psychology concerns understanding psychological causes, while folk physics concerns understanding physical causes. Autism, therefore, is examined in relation to these two types of causal understanding.

It is well established that children with autism have significant impairments in the development of understanding in folk psychology (Baron-Cohen, 1995; Baron-Cohen, Leslie and Frith, 1985; Baron-Cohen, Tager-Flusberg and Cohen, 1993), while they show relatively normal or even heightened development in folk physics (Baron-Cohen, in press; Baron-Cohen, Leslie and Frith, 1986; Frith, 1989; Jolliffe and Baron-Cohen, in press).

Consequently, it is hypothesized that their parents, who carry the genes for autism, might share this cognitive phenotype to a milder degree (Baron-Cohen and Hammer) and may be more likely to engage in professions where "ability" in folk physics is essential, while ability in folk psychology is less important. Engineering is an example of such a profession, as it primarily involves a good understanding of objects rather than people, and it is not as rare an occupation as theoretical physics, for instance.

In a study conducted in the United Kingdom, it was found that the parents of individuals on the autism spectrum shared this cognitive phenotype and were overrepresented in engineering as a profession. Questionnaires were sent to 1,000 parents of children with autism or Asperger syndrome via the membership list of the National Autistic Society, and 919 responses were received. Parents (a total of 40 couples) were asked to report the occupation of both the mother and father of the child, as well as that of the child's four grandparents. Information was collected from four groups: parents of children with Tourette syndrome were used as a control group, in order to check whether the patterns of occupational choices among parents of children with autism or Asperger syndrome were a function of the types of parents involved.

The results strongly confirmed the prediction and showed that parents sharing this cognitive phenotype were overrepresented in engineering as a profession. Indeed, both the fathers and grandfathers of children with autism or Asperger syndrome were found significantly more often in engineering compared to the fathers and grandfathers of other children. Fathers of children with autism or Asperger syndrome were found in engineering at more than twice the frequency compared to fathers from any of the four groups. This was also true for the grandfathers of children with autism compared to the grandfathers of children with Tourette syndrome (TS), suggesting that such occupational patterns operate across at least two generations in families where a child with autism is present.

The percentage of children with autism or Asperger syndrome who had a father or grandfather who was an engineer was 28.4%, whereas for children with Tourette syndrome, the figure was only 15%, a quite significant difference. Furthermore, among the fathers of children with autism, the ratio of those employed in engineering compared to those employed in social fields was 6:1. No significant differences were observed in the rate of engineers between fathers or grandfathers of children with autism versus Asperger syndrome.

This study clearly shows that autism or Asperger syndrome does not occur randomly and suggests that the cognitive phenotype of the fathers of children with autism may be broadly characterized by a strength in folk physics relative to folk psychology. In other words, there is a small but statistically significant connection between autism and engineering. However, this connection between autism and engineering calls for further research. It is important to clarify that the majority of engineers have no link to autism, and the majority of parents of autistic children have no link to engineering.

The association between autism and engineering may shed light not only on autism itself but ultimately on the genetic basis of two essential human abilities: "folk psychology" and "folk physics."

The current findings may also help explain why a condition like autism persists in the gene pool: the same genes that may lead a person to have an autistic child might also lead to high functioning in the area of folk physics. Engineering and related folk physics skills have undoubtedly transformed human life for the better. Without these skills, Homo sapiens would still be pre-industrial.

There is great interest within the scientific community in identifying the genetic basis of these two most fundamental human abilities: folk psychology (also known as mindreading) and folk physics (or open-ended tool use), as these two capacities are considered to have played a dominant role in the evolution of primates (Mithen, 1997; Whiten, 1991).

9. Connection between Autism and Medicine

9.1. Autistic Traits, STEM and Medicine

While medicine is often considered a single field, such a view may be overly simplistic, as medical science covers a wide range of specialties (currently 65 specialties and 31 subspecialties in the UK according to the General Medical Council, 2019). Identifying the factors that influence specialty choice is important for those who train or advise doctors on their career paths, as well as for policymakers aiming to address shortages in certain specialties (Smith et al., 2015). The decision-making process regarding medical career paths is not yet fully understood (Querido et al., 2016), although several contributing factors have been identified. Some of these include the perception of the specialty (Crewther and Cook, 2020; Hill et al., 2014), actual experience (Woolf et al., 2015), work characteristics (e.g., working conditions and location; Cleland et al., 2017), and individual difference variables such as age, gender, and personality (Lambert et al., 2018; Lepièce et al., 2016; Querido et al., 2016). Some of these factors may also interact; for example, compared to men, women have more negative surgical experiences during medical school (Hill et al., 2014) and tend to prioritize working hours that accommodate domestic circumstances rather than seeking prestige (Querido et al., 2016; Smith et al., 2015).

The hypothesis that an individual's personality prompts an attraction to certain professions by developing interests that lead to professional skills (Woods et al., 2016) has led some researchers to examine personality trait differences among professionals across different areas of medicine.

In a study conducted with a sample of UK university students, the relationship between autism and career intentions among medical students was examined, and personality type was investigated in relation to specialty choice. The autistic traits of STEM students versus non-STEM students were explored, along with whether medical students specializing in surgical and technical fields (e.g., radiology, anesthetics) exhibited higher levels of autistic traits compared to students specializing in people-oriented fields (e.g., pediatrics, general practice, hospital medicine). This study provides a preliminary investigation into the prevalence of autistic traits among UK medical students. The main findings are that medical students show lower autistic trait scores compared to other students (both STEM and non-STEM), and that medical students preferring technically focused specialties tend to exhibit higher autistic trait scores than those preferring people-oriented specialties.

There are well-known stereotypes associated with certain medical specialties, many of which seem to focus on doctors' communication and interaction with patients and other healthcare professionals (Oxtoby, 2013). Although there is consensus that personality traits are linked to medical specialty choice (Bexelius et al., 2016; Borges and Osmon, 2001; Borges and Gibson, 2005; Sievert et al., 2016; Woods et al., 2016), findings have not always been consistent. Since these studies used a wide variety of personality measures as well as different criteria for categorizing specialties (Borges and Gibson, 2005), comparing their results has been difficult.

Nonetheless, it is notable that "people-oriented" doctors score higher on empathy compared to "technology-oriented" doctors (Hojat et al., 2001). Physicians in technically oriented specialties were more likely to score high in cognitive structuring and aggressiveness, suggesting they could be characterized as "more precise, demanding, rigid, needing structure, and perfectionistic" (Borges and Gibson, 2005). In contrast, "people-oriented" specialties attracted more socially characteristic doctors, who could be characterized as "empathetic, warm, and friendly individuals" (Borges et al., 2004). These "technology-oriented" and "people-oriented" traits are generally comparable to systemizing and empathizing, respectively, and thus may share similarities with certain characteristics of autism (Baron-Cohen, 2009).

However, more generally, medicine is studied by individuals with lower levels of autistic traits, possibly because the entry requirements (e.g., interviews) for medical school are very demanding. While there is no existing literature specifically examining AQ and performance in medical school interviews, it is clear that non-cognitive traits are important, with interviews selecting for those with higher emotional intelligence and social ability, who are more likely to excel in later clinical exams (Yusoff, 2018). All UK-based medical schools now accept candidates based on a combination of University Clinical Aptitude Test (UCAT) scores and semi-structured/multiple mini-interviews. Thus, it follows that candidates with lower AQ scores are more likely to be selected, introducing a potentially confounding factor in interpreting these results.

The research found no statistically significant gender difference, but there was an interaction between gender and specialty choice. Findings indicated that relatively more women intended to pursue people-centered and general specialties compared to technical specialties, and relatively more men intended to pursue technically oriented roles than people-centered roles.

Studies also show that among UK medical graduates, the female-to-male ratio for those choosing general practice was 2.5:1, and for surgery, it was 1:1.14 (Lambert et al., 2018). This suggests that gender differences in autistic traits may contribute to the persistence of gender differences in specialty representation, despite efforts toward greater equality (Querido et al., 2016).

10. Conclusion

The globalization of the economy and the continuous advancement of technology necessitate that the skills and knowledge required for a specific job are constantly evolving. The demand for labor in the STEM fields constantly increased and individuals with autism spectrum disorder appear to have the potential to play a significant role in achieving this important societal goal. Specifically, this is being achieved among the student in the higher-functioning end of the broad spectrum of intellectual expressiveness, namely among youth with high-functioning autism who are more capable of pursuing their interests in STEM through postsecondary education. Particular attention is given to children with autism spectrum disorder, as the school program was specifically designed to address the skills and challenges associated with the diagnosis, and there is an increasing need for focused attention on this population.

The challenges faced by individuals with autism are well-documented. They include difficulties with social skills, verbal and non-verbal communication struggles, restricted interests, repetitive behaviors, a need for sameness and routine, and difficulty understanding others' intentions or emotions. Individuals with autism may exhibit rigid thinking and process information in precise, less flexible terms. People with autism face important difficulties in almost all metacognitive domains. According to this point of view, Autism could also be characterized as a disorder of metacognition. Many researchers have shown the effectiveness of robots in developing metacognitive skills to autistic children, as well as in improving social skills, emotion awareness and communication. Educational Robotics (ER) is a novel learning approach renowned mostly for its effects on scientific academic disciplines of STEAM.

The extent to which these characteristics are present varies from person to person and may manifest in different ways. Some of these individuals may demonstrate superior visual acuity, heightened attention focus, and strong logical thinking abilities, creating a natural affinity with the fields of science, technology, engineering, and mathematics (STEM). However, no exceptions are made for individuals with autism in their professional trajectory, as their differing needs and abilities are often perceived as deficits.

Compliance with ethical standards

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The Authors proclaim no conflict of interest.

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