Introduction

Public interest in developing and improving STEM education in the United States has grown in response to concerns that the U.S. is losing ground in science and technology. A 2007 report from the National Academy of Sciences warned of a growing erosion of U.S. competitiveness and pre-eminence in development and innovation within STEM fields and advocated for improved workforce preparation and education (Century, 2007). Although some research suggests that this fear is overstated (Rothwell, 2013; Yu & Killewald Alexandra, 2012), STEM is a growing industry that is ripe for workforce development.

At the individual level, STEM-based occupations provide high status and come with high salaries and prestige (Rothwell, 2013; Yu & Killewald Alexandra, 2012). Research shows students who graduate with STEM majors on average earn 25% more than their counterparts (Melguizo & Wolniak, 2012; Olitsky, 2014). At the same time, many perceive STEM careers as having universalistic (or meritocratic) criteria, such as an individual’s level of education or prior work experience, and unaffected by gender, race, ethnicity, class, and religious affiliations (Liu, 2011; Xie, Fang, & Shauman, 2015). However, the promise of high status and reward does not translate necessarily to attained high status and reward for everyone. Employment, wage, and on-site discrimination persist in STEM fields (Broyles, 2009; Broyles & Fenner, 2010). Prior to joining the labor market, students face unequal access to high-quality STEM education in the United States, thereby affecting their career opportunities. Leveling disparity in access to STEM education and careers can introduce historically disadvantaged groups into the workforce and spur innovation.

Tutoring has the potential to ameliorate some of these existing inequalities in STEM education and the STEM field, at large. To improve our understanding of these possibilities, this memo will:

- explore the inequality in STEM education;
- propose tutoring as an effective intervention to promote equality; and
- propose considerations for developing and evaluating a tutoring intervention.

Our literature review finds that systemic and institutional inequality affect STEM education, but tutoring interventions can alleviate some of these issues facing students. Tutoring interventions can benefit both tutees and tutors, so a rigorous evaluation of a tutoring intervention will measure impacts on both populations.
Inequality in STEM education

Context matters in determining success in STEM education. From a school’s funding to a student’s history, many macro and micro factors contribute to the inequality in STEM education in the U.S. This section focuses on the most predictive social determinants of STEM education. They include school contexts, class, gender, and race.

School contexts

The K-12 schools that students attend can affect STEM education and preparation for postsecondary STEM specializations. Because K-12 schools differ widely in resources for STEM, students do not receive the same access to the same quality of STEM education (Museus, Palmer, Davis, & Maramba, 2011; M.-T. Wang, Eccles, & Kenny, 2013). Not surprisingly, well-resourced schools offer a greater selection of math and science courses and greater access to resources (Oakes & Saunders 2004).

School climate also may play a role in STEM education, motivation, and confidence. There are four main components of school climate: safety, community, academic, and institutional environment (M. Wang & Degol, 2016). Most research on school climate and STEM education have focused on the academic environment. For instance, students’ access to knowledgeable and experienced math and science teachers shapes students’ interest and passion for STEM education (Xie et al., 2015). Similarly, at the postsecondary level, students receiving more encouragement from faculty and other students, sufficient financial aid, and networking opportunities are more likely to graduate with STEM degrees (Museus et al., 2011). Opportunities to participate in an undergraduate research program significantly improves students’ probability of self-reported planning to enroll in a STEM graduate program (Eagan et al., 2013). Empirical evidence suggests resources dedicated to improving school climate also improves students’ psychological, social, and academic development in general education (M. Wang & Degol, 2016). Despite this, more research is needed to describe the different school climate factors and their effects on STEM participation, academic achievement, and career trajectories.

Class

Students’ socioeconomic background plays a substantial role in STEM participation and persistence. Students with high socioeconomic status (SES) may receive more emotional support and educational resources for pursuing STEM interests when they are young (Xie et al., 2015). A disproportionate number of students obtaining STEM degrees and pursuing STEM careers come from high-SES families (Chen, 2009). Yet, when academic achievement and other factors are controlled, analyses show that the effect of SES on graduation with a STEM degree is reduced (Yu & Killewald Alexandria, 2012). In other words, students’ socioeconomic backgrounds indirectly affect their academic momentum in completion of their degrees, but do not affect directly their attainment of STEM degrees (Attewell, Heil, & Reisel, 2012).

Gender

Gender is a strong predictor of whether students attain postsecondary STEM degrees. Research shows that female students score equally well or better than their male classmates in grades K-12 on standardized test scores and course grades in math and science (Cheema & Galluzzo, 2013; Kenney-Benson, Pomerantz, Ryan, & Patrick, 2006). However, female students are more likely to report lower self-confidence in math abilities, lower interest, and lower motivation to learn math and science, even when the level of math and science achievement is on par with their male counterparts (Cheema & Galluzzo, 2013; M.-T. Wang et al., 2013). Confidence and interest in math and science are tied to the educational and social
environment in which the student is embedded. Stereotyping (e.g., that math and science are for boys) and visible social and economic inequality contribute to this gap (Cheryan, 2012). Research suggests that greater exposure to math-related environments and increasing presence of role models and media can ameliorate the gap (Cheryan, 2012). Furthermore, providing more support and resources for women to engage in gender role-consistent behaviors without having to take away from their pursuit of STEM education and careers (for instance, providing child care) may help these students tend to existing gender roles while also challenging them (Cheryan, 2012). Developing strong mentoring programs may help provide the social-psychological and resource support needed to cultivate further the talent of aspiring female STEM students (Malcom & Malcom, 2011).

**Race**

In recent years, the number of underrepresented minorities (URMs)—Black, Hispanic, and/or Native American students—has increased in STEM fields. However, large gaps in STEM test scores, course participation, and course grades between URM students, and White or Asian students (National Center for Education Statistics (NCES), 2013) persist. This difference is even more pronounced among high-achieving students. The test score gap between URM students and White or Asian students in elementary school increases at a substantially higher rate among high-achieving students than it does among low-achieving students (Olitsky, 2014; Reardon & Bischoff, n.d.). As the gap continues to increase after elementary school, URM students tend to take fewer and less challenging math and science courses than White or Asian students (Kelly, 2009; Riegle-Crumb & Grodsky, 2010), and are overrepresented at two-year and less prestigious four-year institutions (Xie et al., 2015). Yet, elite graduate programs and industries disproportionately select applicants from mainstream elite universities (Xie et al., 2015).

Three factors explain the racial gaps in STEM education. First, the environment affects social-psychological factors. URM students at the postsecondary level are more likely to report feelings of isolation and trouble adapting to White, middle-class culture of science (Chang, Sharkness, Hurtado, & Newman, 2014). Second, lower rates of graduation in a STEM field among URM students can be attributed to racial gaps in K-12 academic preparation (Yu & Killewald Alexandra, 2012). Third, large structural issues of segregation, especially by residence, continue to sustain and exacerbate educational inequality (Reardon & Bischoff, 2011).

Overall, inequality persists within general and STEM education, and they affect students’ motivation, academic achievement, and participation in STEM fields. As part of Mayor deBlasio’s educational initiative – *Equity & Excellence For All* – CUNY Tutor Corps aims to increase New York City student performance in STEM disciplines and to attract more college students majoring in STEM disciplines to move into the teaching profession. The program employs undergraduate and graduate level STEM students to tutor middle and high school students in Algebra and Computer Science. After receiving training in a two-week immersion, tutors work at their assigned schools for 12 hours per week. In order to better inform program implementation, we review strategies for implementing tutoring in the literature. We also examine how tutoring can bridge some of the gaps that exist in both K-12 and postsecondary education in the next section.

**Intervention Models and Practices**

Tutoring is an effective teaching model used to supplement classroom instruction (Bloom, 1984). Unequal resources to hire tutors exacerbates the achievement gap between
students from high income families and students from low income family (Duncan & Murnane, 2011) because high income families have more resources to hire tutors. Tutoring interventions, such as CUNY Tutor Corps, inject resources into disadvantaged communities. Most tutoring interventions target elementary school reading. However, previous research suggests that tutoring is more effective for mathematics than reading or social studies (Robinson, Schofield, & Steers-Wentzell, 2005a). Commonly, tutors are peer or cross-age volunteers, who also act as mentors. CUNY Tutor Corps’ model of paid cross-age tutoring for math and computer science is fairly unique. There are similar interventions at Auburn University, Wayne State University, and Columbia University, but these programs have not been robustly evaluated and little is known about their effects. In this section, we define tutoring as supplemental instruction conducted by paraprofessionals – as employees or volunteers. Instructions vary: some tutors assist targeted students with homework, others conduct office hours, still others diagnose students’ challenges and begin early-stage prognosis.

**Tutoring Interventions**

Tutoring interventions vary widely in their components and their effects. Sources of program variation include: tutee age and skill level, tutor age and type, tutor training, format of tutoring, frequency and duration of tutoring, instructional approach, and tutoring content (Center for Prevention Research and Development, 2009; Cohen, Kulik, & Kulik, 1982). Following is a discussion of the relationship between these program components and outcomes, as well as established best practices.

**Tutee age and skill level.** Researchers have tested math tutoring across a variety of ages. Evidence indicates it is an effective intervention for improving academic outcomes in elementary through high school students (Robinson et al., 2005).

**Tutor age and type.** One study suggests that tutees’ academic gains are smaller when there is a larger tutor - tutee age gap. This may occur because tutors are teaching simpler content than their coursework (Robinson et al., 2005). Thus, the recommended age gap for cross-peer tutoring is between 2 and 4 years. At 6 – 7+ years, academic gains for the tutors diminishes. (Robinson et al., 2005). Additionally, while most cross-age tutoring programs select high-achieving tutors, research suggests that lower achieving tutors and their tutees experience similar benefits (Robinson et al., 2005).

**Tutor training.** Tutor training is crucial to ensure fidelity to the intervention model. Few studies report on tutor training. Additionally, their brief description of training does not include measures of training quality (Robinson et al., 2005). However, these studies do suggest that tutors benefit from training. Important training components include: interpersonal skills, management skills, and content (Robinson et al., 2005). Training should include role playing, with feedback or coaching during the actual session (Hock, Pulvers, Deshler, & Schumaker, 2001; Robinson et al., 2005). Tutors who receive ongoing training outperform tutors who do not (Center for Prevention Research and Development, 2009; Wasik & Slavin, 1993). A crucial training component often neglected is training teachers how to work with tutors. Possible topics for teacher training include: classroom noise level, physical layout of the classroom, scheduling and curriculum (Robinson et al., 2005).

**Frequency, duration, and dosage of tutoring.** Meta-analyses of tutoring interventions suggest that tutoring sessions should be no longer than 60 minutes (duration), occur at least three times (frequency) a week, and total at least 45 hours of implementation (dosage) (Center for Prevention Research and Development, 2009).

**Instructional approach.** Potential instructional approaches include instructional tutoring, assignment assistance tutoring, and strategic tutoring. During instructional tutoring, tutors provide one-on-one instruction for specific content. Assignment assistance tutoring consists
of individual or small group (two to six students) tutoring focused on assignment completion. Strategic tutoring teaches tutees both learning and content strategies through work on assignments. Strategic tutoring provides tutees with meaningful and transferrable skills to sustain and even promote greater academic gains after tutoring has ended and encourages students to become engaged learners (Hock et al., 2001).

**Tutoring content.** Research on peer tutoring in a heterogeneous classroom suggests tutoring is more effective for lower order skills, such as computation and problem solving, than higher level skills. This is especially relevant for algebra classes, which include a mix of low and high level skills (Allsopp, 1997; Robinson et al., 2005).

Researchers identified the following best practices to inform program development: defined time commitment, systematic screening and tutee matching, training of tutors, collaboration between schools and college, frequent tutoring sessions over a long duration, monitoring implementation (Moss, Swartz, Obeidallah, Stewart, & Greene, 2001; Petry & Armitage, 1990; Robinson et al., 2005).

**Teaching-Learning Environments**

Besides tutoring best practices, the context for tutoring in the teaching-learning environment is equally important for the successful development of students' motivation, academic achievement, and participation in STEM fields. In this section, we examine three core components that contribute to the teaching-learning environments: (1) tutor-tutee relationship; (2) tutor-teacher relationship; and (3) informal learning spaces.

**Tutor-tutee relationship.** Research shows a connection between tutee's comfort with tutor and tutee's perceived competence of tutor. Additionally, the composition of tutor-tutee dyad, in regards to gender, age, and race similarities or differences, affects the relationship and outcomes. Same-sex tutoring dyads are associated with greater student gains than those in mixed sex dyads. Research has not examined the effect of race in secondary school tutoring dyads nor the intersection between race and gender (Robinson et al. 2005).

**Tutor-teacher relationship.** The tutor-teacher relationship is unique and understudied. This relationship is crucial for tutee success and helps to build teacher capacity. Tutor-teacher relationship that aims to develop and establish pedagogical knowledge and skills of the tutors can improve tutees’ academic success while lessening teacher’s workload over time. (Ragonis & Hazzan, 2008).

**Informal learning spaces.** Informal learning environments are crucial to the support of students' success in STEM-based programs (Denson, Hailey, Stallworth, & Householder, 2015; Walker, 2006). These environments are separate from the classrooms and fuse emotional and intellectual learning; informal learning spaces – through spatial or temporal distance from the classroom, distinct social setting, and institutional contexts – emphasize participation and development, not what individuals accomplish (Martin, 2004). Tutoring can provide new informal learning spaces that provide opportunity for both the tutor and the tutored to refine their understanding in math (Walker, 2006). In informal learning environments, students engage in informal mentoring that can make learning fun, builds community, and provides exposure to new opportunities. As a result, these environments can contribute to learning in STEM and developing interest in STEM fields and careers (Denson et al., 2015). When informal learning spaces are available, the spaces can encourage students to form their own study groups. This can increase students’ GPA, reduce anxiety toward math and sciences, improve
students’ confidence in math, and increase overall personal self-esteem (Lam, Srivatsan, Doverspike, Vesalo, & Mawasha, 2005).

**Considerations for Evaluation**

This literature review suggests contextual factors that affect STEM education and may influence tutoring interventions. As CUNY Tutor Corp begins its pilot year, a rigorous evaluation methodology will help to gauge the program’s capacity to affect the different factors in STEM education. The program alone will not transform disproportionalities in access to STEM education, but it has the potential to affect both tutors and tutees. In this section, we propose examining outcomes of tutors and tutees and implementing a rigorous quasi-experimental study of Tutor Corps’ pilot year.

**Outcomes**

The intervention model informs the outcomes of interest. A logic model or theory of change should link the outcomes to the intervention components. Previous studies examined outcomes at multiple levels, including tutee, tutor, teacher, and interactions between these individuals. Given Tutor Corps’ unique employment of CUNY students to tutor NYC high- and middle-school students, we propose examining outcomes for both tutees and tutors.

Previous studies of tutee outcomes measured students’ academic and socio-emotional gains. Academically, the most often used measure is standardized test scores, although specific algebra progress monitoring tools have been developed (Foegen, 2008). Outcome measurements of tutees should take advantage of studies of previous measures including: student attitudes toward the tutored subject, self-rating of scholastic competence, belonging, social competence, self-esteem, and self-concept (Robinson et al., 2005). Previous research suggests these individual characteristics moderate outcomes (Robinson et al., 2005).

Tutoring interventions can benefit tutors, too. They may experience improved attendance and academic performance in subjects within and outside the scope of their tutoring. However, most of this research sampled high school student tutors (Robinson et al., 2005). Tutor Corps will need to build on this research and develop outcome measures that encapsulate impacts of tutoring on college tutors.

**Methodology**

Previous research on and evaluations of tutoring interventions employed methodologies of varying rigor. The most rigorous methodologies are experimental or quasi-experimental studies, using random or stratified random assignment. However, it is often impossible to randomize subjects in real-world conditions. Thus, we propose using propensity score matching to evaluate Tutor Corps’ pilot year. Propensity score matching is a statistical technique that will estimate the effect of the tutoring intervention by controlling for the factors that predict receiving it. Another challenge when conducting highly applied research or evaluation is identifying and controlling confounds. Potential confounding factors of the Tutor Corps intervention include:

- Teacher-chosen tutees
- Tutor application process
- Multiple tutors providing instruction to a single tutee
- School selection process
- Algebra for All/CS for All teacher training (spillover effects)

There will certainly be variation between Tutor Corps’ schools. Measures of implementation are necessary to control for this variation. Without these measures we cannot examine
moderating effects, such as frequency and duration of tutoring sessions, this is especially important, as weak or null findings may be explained by low fidelity (Robinson et al., 2005). Implementation measures include:

- Math Problem Solving Strategy Checklist (Hock et al., 2001)
- Strategic tutoring checklist (Hock et al., 2001)
- Tutoring session feedback form (Ragonis & Hazzan, 2008)

Abt Associates for AmeriCorps, a Corporation for National & Community Service Program, conducted an exemplar model for an evaluation of a large scale tutoring intervention. Although AmeriCorps provides tutoring for reading, the design is highly applicable to Tutor Corps. The Tutoring Outcomes Study sampled 869 students at 68 program sites. The study collected data on academic and socioemotional outcomes, as well as implementation. Specifically, the measures assessed reading performance, classroom behavior, tutor experiences, and program characteristics. Analysts used hierarchical linear modeling – an advanced statistical technique – to measure student and program effects.

Other topics for future exploration include:

- Training – What knowledge or skills do tutors gain during tutor training?
- Training – Do tutors apply training concepts in practice?
- Training – What is the effect of ongoing training or supervision?
- Tutors as role models
- Tutor – teacher relationship – Is tutoring an effective strategy to build teacher capacity in computer science?
- Tutee selection – Which students benefit most from tutoring?
- Tutor selection – Which tutors are effective? Which tutors benefit academically?
References


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