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Cognitive and Non-cognitive Skills Acquisition in Disadvantaged Populations: Evidence from the Nurture thru Nature (NtN) Experiment[1]

Radha Jagannathan & **Michael J. Camasso**, Rutgers University

Abstract

It is widely acknowledged that our public schools have failed to produce sufficient levels of high quality STEM education. The mathematics and science performance of minority and disadvantaged students has been especially troubling with blacks and Hispanics substantially underrepresented in the STEM labor market. In this paper we examine the impacts of a STEM enhancement program called Nurture thru Nature (NtN) on the cognitive (academic grades) and soft skills development of 139 elementary school students who attended the program over an eight year period (2010-2017). Utilizing a randomized experimental design or RCT with a control group of 491 elementary school students, we find that NtN slows the deterioration in students' math and science grades relative to controls and improves soft skills such as conscientiousness, higher order thinking, empathy, and pro-social behavior.

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1. Introduction

In a report issued by the Business Roundtable (2017) a troubling picture of the U.S. workforce is presented that depicts too few workers with specialized STEM skills and abilities. Especially alarming are the deficits found in math and science knowledge and skills, computer skills, mechanical skills and operations monitoring capabilities (Stewart, 2018; Rothwell, 2013). The same Business Roundtable report notes that an increasing number of job applicants lack fundamental employability skills as well, i.e., the ability to "communicate effectively, read technical manuals, work successfully in teams and participate in complex problem solving" (p.1). This set of skills along with clarity of oral expression, listening skills, the ability to motivate others and conscientiousness are believed by many labor economists and business leaders to comprise a panoply of "soft" or non-cognitive abilities, critical for successful labor force participation (Heckman, Stixrud and Urzua, 2006; Cunha and Heckman, 2008; Ibarraran et al., 2014; Attanasio, 2015; Stewart, 2018). Data published by the Manufacturing Institute (2016) and by the Bureau of Labor Statistics indicate that the scarcity of math, science and soft skills is most pronounced for African Americans and Hispanics (National Science Foundation, 2016; Committee on Highly Successful Schools or Programs, 2011), excluding many of these individuals from the higher wages and job security that accompany employment in STEM occupations.

Poor preparation for careers in STEM occupations is especially acute in urban public schools. A Science and Engineering Indicators report released by the National Science Board (2016) concludes that students in disadvantaged school districts are most affected by deficiencies in STEM education. The Board concluded that "fully certified mathematics and science teachers were less prevalent in high minority and high poverty schools" (p.5) and that a lower proportion of math and science teachers held in-field degrees and had extensive teaching experience. A number of careful analyses of academic achievement differences in disadvantaged and more privileged schools, moreover, have yielded three important insights, viz., educational deficits are cumulative, they are accelerated in the summer, and these accumulating deficits are not limited to cognitive knowledge and skills. Fryer and Levitt (2004), Heckman (2013), and Heckman and Masterov (2007), among others, report that the already substantial differences in human capital investments between disadvantaged and more privileged students observed at entry to school increase with age. In their 25-year study of achievement in STEM education, Wai et al. (2010) conclude that disparities in science and math performance emerge early in elementary school and worsen over time. By tenth grade, black and Hispanic students are more likely than their white and Asian peers to filter into low education tracks and less likely to pursue STEM courses. Hill (2017) notes that growth curve analyses indicate learning increases more in elementary school than it does in middle school, and this deceleration is most pronounced in disadvantaged school districts. Because of this accumulating effect and the widening achievement gap it creates, labor economists and child development professionals have called for "predistribution" or early intervention strategies of investment. Heckman (2013) sums up this growing consensus when he asserts that "programs targeted toward the adolescent years [or later] of disadvantaged youth face an equity-efficiency tradeoff that programs targeted toward the earlier years of the lives of disadvantaged children avoid." (p.40).

It is also becoming more apparent that increases in the disadvantaged-privileged and white-minority academic achievement gaps are not steady state; rather, abrupt increases in the size of the gaps occur after each academic year and summer recess (Alexander, Entwisle and Olson, 2007; McCombs et al., 2011). Hanushek and Rivkin (2009) state that a consistent finding in the research literature is the phenomenon of "summer fallback" which suggests that while learning during the school year might, on average, be the same for white and minority students, the amount of learning in the summer months heavily favors white students (p.370).

Lastly, learning deficits between privileged and disadvantaged students have been shown to occur in socio-emotional as well as cognitive skills (Coleman, 1990; Heckman, 2000; Heckman and Kautz, 2012; Ibarraran et al., 2014; Attanasio, 2015; Golden, 2018;). Carneiro and Heckman (2003) maintain that a series of soft or "civic skills," e.g., perseverance, attentiveness, motivation, self-confidence, self-discipline, trustworthiness and dependability, are developed early in a child's life and are critical for success in school, the labor market, and life. What's more, these non-cognitive skills serve to promote the acquisition of cognitive skills early in a child's development; the relationship does not appear to be reciprocal, however (Cunha and Heckman, 2008; Cunha, Heckman and Schennach, 2010).

While many gaps remain in our knowledge of human capital formation, two things have become increasingly clear: (1) skill and ability formation exhibit dynamic complementarities and interactions, i.e., abilities beget skills and more skills increase abilities (Heckman, 2000; Attanasio et al., 2017); and (2) efforts to build an individual's technical and soft skill portfolios yield their highest returns to investment when introduced at a young age, certainly well before entry to high school (Bagiati et al., 2010; Maltese and Tai, 2011; Cunha and Heckman, 2008). Tai et al (2006), for example, find that an early interest in pursuing a science-related career increased a child's chances of actually completing a science or engineering degree by about three and a half times. And increasingly the provision of "extra-school" robust natural and environmental science teaching, introduced at the elementary school level, has been identified as a promising pathway to STEM and green careers (Clarke, 2012; Royal Horticulture Society, 2010; U.S. Department of Education, Green Ribbon Schools, 2018).

In this paper, we examine how a natural science focused STEM enhancement program titled Nurture thru Nature (NtN) can increase the technical and socio-emotional skills of disadvantaged black and Hispanic students from seven elementary schools in Central New Jersey, who were randomly assigned to treatment and control groups (RCT). Inspired by the active learning philosophy of John Dewey (1976, 1990) and its extension in the forms of the outdoor education movement (Ord and Leather, 2011; Quay and Seaman, 2012) and wonders of nature teaching model (Camasso and Jagannathan, 2018; Jagannathan, Camasso and Delacalle, 2018), NtN focuses on the concomitant improvement of STEM cognitive skills and a set of socio-emotional or 'soft skills' that help facilitate the acquisition of the former.

2. The Nurture thru Nature (NtN) Experiment

The NtN program was initiated in 2010 as the community partnership of Rutgers University, the Johnson & Johnson (J & J) pharmaceutical company headquartered in New Brunswick, New Jersey, and the New Brunswick Public School (NBPS) district to enhance the STEM knowledge and skills of disadvantaged minority students in the district. The program was designed as a classical experiment with random assignment of students in their 3^{rd} grade into the NtN and control groups. The program provides STEM enrichment activities to students selected into the program group until they graduate high school. Students typically meet 2-3 times a week for 3 hours during the school year and 3 days a week for 7.5 hours per day in July and August.

Nurture thru Nature (NtN) attempts to overcome the limitations of some environmental science interventions targeted at disadvantaged youth through a program of clear conceptualization of purpose, sufficient treatment dosage, and strong evaluation design. NtN draws heavily from the seminal work of John Dewey, recognizing that children are never passive recipients of education but rather are actively engaged agents in their own life's dramas. There is an additional recognition that young students, regardless of background or family resources, have a wellspring of uninvested human capital that can be directed into communication, construction, inquiry, and abstract thinking if teaching takes a personal approach, understanding how student interests and habits derive from their homes and neighborhoods (Dewey, 1976:p.30; Dewey, 1990:p.463). Like other STEM enrichment programs, NtN programming makes the assumption that participation will increase STEM exposure and skills; this, in turn, will translate into stronger orientations which will help students develop technical and soft skill competencies. What distinguishes NtN is a "naturalist approach" to gaining STEM "identities" and competencies through the intensive use of school naturescape/gardens, interactions with live plants and animals, outdoor and lab experimentation, and observation and taxonomic learning methods.

NtN has five core components, viz., (1) a grade-specific STEM-centered curriculum aligned with the curriculum taught by public school science and math teachers; (2) after-school and summer components that reinforce school curriculum; (3) math, science and language arts tutoring; (4) the use of garden/naturescape and indoor lab assets that extend indoor classroom; and (5) a commitment to keep parents aware and involved in their child(ren)'s math and science education. The NtN curriculum for the last two years of high school also incorporates school-to-college and school-to-career activities such as SAT prep classes, college visits, exposure to STEM careers through guest lectures from Johnson & Johnson professionals as well as scientists from Rutgers University, and internship opportunities at various Rutgers professional schools and local non-profits. An outline of NtN's STEM curriculum content areas and the context of where content is implemented appear in Figure 1. A more detailed description of these curricular components and after-school and summer operations can be found in Camasso and Jagannathan (2018) and Jagannathan, Camasso & Delacalle (2018).

[Figure 1 about here]

3. Data and Methods

Sample Characteristics, Study Variables and Data Sources

Data used to test NtN impact are generated using a classical experiment, with students randomly assigned to the NtN group and a control group (RCT) in seven New Brunswick, NJ elementary schools[2]. Random assignment helps (a) alleviate concerns about selection bias that is very common in observational studies, (b) generate differences in outcomes between groups that are otherwise statistically similar, and (c) obviate the necessity of using schoolteachers/ counselors as judges of student fitness for NtN, thereby minimizing the outcry of the parents of unselected students around issues of "favoritism." In addition to using the random assignment procedure to select students into NtN and control groups, we also randomly drew students to populate a 'Waiting List' from which students could be selected to become a part of the program if students who were already selected needed to withdraw for some reason or dropped out of the program at a later date. For each of the 8 cohorts, sample selection was conducted through a lottery when students were in the end of 3rd grade or beginning of 4th grade after stratifying by classroom[3]. The lottery numbers were drawn by the School Principal and the 'winners' were assigned to the NtN group, and the remaining students comprised the control group. The first 20 numbers drawn identified NtN students and the last two numbers drawn within each classroom and gender group identified students who were placed into the waiting list.

NtN began with the first cohort of 19 students in the summer of 2010 when these students had completed 3rd grade. Subsequent cohorts were drawn in 2012 (2 cohorts), 2013 (1 cohort), 2014 (3 cohorts) and 2015 (1 cohort) as more funding became available. Because of the phased-in way in which the sample was accumulated, NtN participants had differing years of program exposure. For example, as of 2017, the first cohort had 8 full years of NtN participation, while the last cohort had only 2 full years of NtN exposure. The sample contains a total of 630 students, with 139 students in the NtN group and the remaining 491 students in the control group.

The measures that NtN employs to determine if the program is, indeed, raising cognitive and soft skill competencies derive from two sources. The principal measure of technical performance is the academic year-end grades in math, science, and language arts reported by the school district to the New Jersey Department of Education. These grades are collected for each

[2] Two cohorts were selected from one elementary school two years apart.

[3] As a sensitivity check to determine if these lottery strata (i.e., initial classroom assignment) have any bearing on our treatment effects, we re-estimated our regressions including dummy variables for the lottery strata. Incorporation of the lottery effects into our models made little difference with respect to treatment effect estimates (either coefficients or effect sizes). These results are available from the authors.

NtN and control group student at the end of 3rd grade (baseline) and at the end of each subsequent academic year until the student graduates, moves out of district, drops out of school, or otherwise attrits.

The determination of NtN's impact on soft skill acquisition is derived from student self-reports on the NtN Knowledge, Skills and Abilities Inventory (NtN-KSAI). As in the case of academic grades, information on the NtN-KSAI is collected at the end of 3rd grade (baseline) and at the end of each subsequent school year for both NtN and control group students. One question, asks students to rate how good they are at performing 20 skills[4]. This skills list was informed by previous work conducted by Garcia (2014), Platt (2008), Gutman and Schoon, 2013; Judge et al., 1999; and Marsh et al., 1986). These 20 items were factor analyzed to create 4 factors for use in our multivariate analyses: (a) overall soft skills, (b) pro-social behavior, (c) higher order thinking, and (d) conscientiousness.

Analytic Approach

Longitudinal data permit the systematic assessment of stability and change over time and can provide valuable insights into the course and causes of many social behaviors. Here we use a multi-level model, often known as hierarchical linear model (HLM). These models permit straightforward examination of both *intra*-unit (within unit) change over time and *inter*-unit (between units) variability in intra-unit change.

4. Results

We provide a visual summary of NtN impact on both the hard and soft skills outcomes we have considered in Figure 2. These graphs clearly show NtN's role in slowing the decline in cognitive skills and enhancing the growth in soft skills. Numerically, these pictures translate to the following NtN impacts:

- NtN students experience an increase of 0.43 standard deviations in their math grade relative to the control group.
- NtN increases students' science grades relative to the control group by 0.39 standard deviations.
- There are no significant impacts of NtN on students' language arts grades.
- NtN increases students' pro-social behavior (communication, teamwork, empathy) by 0.82 standard deviations relative to the control group.
- NtN students' higher order thinking skills (problem solving, leading a group, thinking creatively and generating new ideas, making presentations) improve by 0.8 standard deviations over the control group's scores.

[4] These skills included solving problems, listening to others, talking to others, working on your own, working with others, asking questions/gathering information to solve problems, reading and understanding written text/instructions, writing reports, making presentations, thinking creatively and coming up with new ideas, testing ideas about science, being sensitive to others' feelings, solving math problems, conducting science labs/experiments, using computers, making decisions, leading a group, being on time, always doing what you said you were going to do, not giving up on a task that is too hard to finish.

- NtN participants experience an increase of 0.79 standard deviations in their conscientiousness (being sensitive to others' feelings, being on time, always doing what you said you were going to do, not giving up on a task that is too hard to finish) relative to non-participants.

In addition, more recent follow-up data shows that:

- Hundred percent of NtN students in the both high school cohorts graduated high school (relative to general New Brunswick graduation rate of 72%).
- Eighty-six percent (86%) of the first cohort of NtN high school graduates (class of 2019) enrolled in higher education (50% attending 4-year colleges and 36% attending 2-year colleges). Similar percentages were observed for succeeding cohorts (2021 and 2022). This is in comparison to the general New Brunswick student college attendance rate of 47%.

5. Discussion and conclusions

The low number of U.S. students pursuing careers in STEM disciplines has grave implications for the health of our nation's economy and democracy. Inadequate academic preparation of students in our elementary and middle schools, especially those living in disadvantaged school district, increase the likelihood that these children will have difficulties in high school and, if they graduate, in higher education and the labor market. Failure in science and math courses is almost certain to eliminate these students from high-paying STEM jobs and careers in the health professions. Complicating matters even more is the evidence that as STEM technical skills freeze or erode, so do soft skills and the social capital that is necessary for labor market success (Heckman, 2013; Heckman and Masterov, 2007).

The moderate impact of NtN on cognitive skills and the larger effects on soft, socio-emotional competencies is a departure from much of the research we have discussed, that has focused on extra-school, STEM enhancement programing directed at minority and disadvantaged youth. We believe there are several reasons that contribute to the magnitude of our findings. First, the NtN intervention starts at a young age, the beginning of 4th grade, when interventions have been consistently found to yield their highest returns to investment (Schweinhart et al., 1993; Ramey et al., 1988; Maltese and Tai, 2011; Cunha and Heckman, 2008; Tai et al., 2006). Many of the rigorous evaluations of extra-school program that we have cited earlier in this paper (e.g., Career Academies, the Quantum Opportunities Program, ECHSI, MESA, and BELL) begin in late adolescence or early high school, at a time when STEM identities are more difficult to mold (Laurer et al., 2006; Ord and Leather, 2011).

The second reason for the relative success of NtN is its implementation of a Dewian active learning philosophy (Dewey, 1976) within the framework of outdoor education (Ord and Leather, 2011; Quay and Seaman, 2012) and the "wonders of nature" curriculum and teaching model (Camasso and Jagannathan, 2018; Jagannathan, Camasso and Delacalle, 2018). Through a program that promotes the conjoint reinforcement of after-school, summer immersion, in-school curriculum extension, involved parents and dedicated NtN teachers who are proficient in math and science, NtN actively confronts the issues of “low dosage” and underpowered treatment that often affect STEM enhancement programs targeting disadvantaged students (McCombs et al., 2011; Levine and Zimmerman, 2010).

The third determinant of NtN impact, we believe, resides in the organizational partnership of Rutgers University, J & J and NBPS alluded to earlier. Active involvement of the University and J & J, through availability of scientists, laboratory facilities, careers exposure and (in the case of Rutgers) college students actively pursuing STEM and health care education and emphasizing the importance of technical and soft skill development has been critical in the process of creating STEM identities in NtN students. A similar partnership between Northwestern University, the Boys and Girls Club, and Chicago Public Schools also reports positive technical and soft skill improvement after a RCT evaluation.

Of course, NtN effects are subject to the vagaries of time and future circumstance. Like effects in the 21st CCLS program or the Highscope Perry Preschool or Abecedarian Project (Heckman, 2000), NtN impacts, too, may diminish or even extinguish when these students begin their college or vocational careers. It is apparent for this research, that cognitive skills of NtN students (measured as math and science grades) decline as they advance through an increasingly more difficult curriculum. This finding with a sample of disadvantaged youth is not new with similar results reported by Hanushek and Rivkin (2009), Alexander, et al., (2007), Wai et al. (2010), and Hill (2017). NtN’s capacity to attenuate this decline is a finding that merits additional verification, ideally employing longitudinal data from other, natural science based extra-school programs.

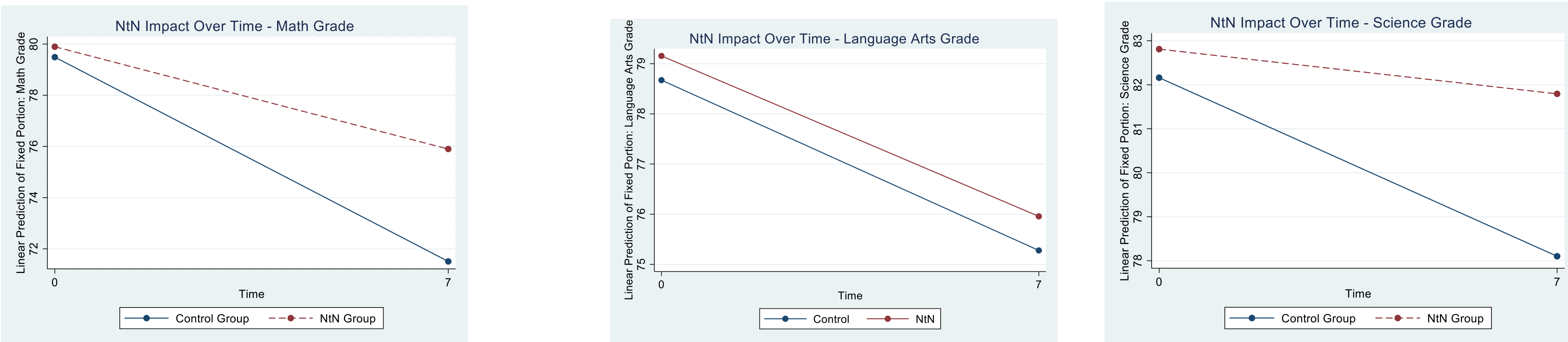
Our findings with respect to the acquisition of soft skills are also encouraging. NtN students performed significantly better than controls on pro-social skills (communication, teamwork, empathy), higher order thinking and problem solving, and conscientiousness. If previous research is to serve as a guide, we would expect these skills to exhibit greater endurance, requiring less reinforcement learning through adulthood (Heckman, 2000; Levine and Zimmerman, 2010; Boscia, 2013: Kemple and Willner, 2008; James-Burdumy et al., 2005).

NtN makes a conscious attempt to bring to life the “University Elementary School” envisaged by John Dewey (Dewey, 1976; p.92-95). Of course NtN’s attempt to operationalize the University Elementary School is subject to challenges that were all but impossible to see a century ago when Dewey first proposed the idea. Skyrocketing numbers of single parent homes, escalating levels of drug use and gang violence, etc., have made it more difficult to transport young students into a natural science world of exploration, excitement, and wonder. Notwithstanding these obstacles this journey remains as important as it ever has been.

Grade Level	School Curriculum Focus	NtN Instruction	
		After School Program	Summer Program
Fourth Grade	Basic Astronomy, The Human Body, Rocks and Minerals	Rocks and Minerals, The Human Body STEM- Make your own Slime, Sugar Water Density, anti-gravity water, rock candy, skewed balloons, clouds activity	Basic Astronomy, Birds, Insects, Reptiles and Amphibians
Fifth Grade	Mixtures and Solutions, Elements and Atoms, Principles of Anatomy	Principles of Anatomy, Mixtures and Solutions STEM- EGG Bungee Jump, Touchdown Activity, Bouncy Ball Activity, Slime Activity, Make your own fidget spinners, balloon powered cars	Fish, Pond Life, Basic Horticulture, Flowers
Sixth Grade	Forces and Motion, Electricity, and Basic Physics, Heat Transfer, The Human Brain	The Human Brain, Newton's Laws, The Scientific Method, Experimentation STEM- LED Projector, lava lamp, balloon hovercraft, foosball table, kinetic sculpture, electrolysis of water, lemon battery, Oobleck	Naturalistic Methods, Evolution and Ecologic niches, Photosynthesis
Seventh Grade	Acids and Bases, Mitosis and Meiosis, Osmosis and Diffusion, Basic Cell Biology	Cell Biology, Lab Reports, Principles of Micro-Biology, Eukaryotic and Prokaryotic Cells STEM – Re-growing cabbage, make a kite, oobleck, static electricity, gliders	Microscopic Pond Life, Healthy Foods and Nutrition, Gardening Techniques / Naturescape Development
Eighth Grade	Processes of Science, Forces and Motion, Energy Transformations, Light, Heat, Solar Energy and Weather, Rocks and the Rock Cycle, Geological time	Atoms and Elements, Evolution, The Processes of Science, Substances, Molecules STEM- rubber band helicopter, LEGO flashlight, propeller powered car, mini robot, fidget spinners, cork launcher	Tree Identification and Uses, Solar Energy and Weather
Ninth Grade	Biology - Evolution, Genetics	Saturday Program- Evolution, Genetics STEM- holiday circuits, levee, rube Goldberg machine, paper bridge	Critical Thinking, Statistics, Pig Dissection, Mentoring
Tenth Grade	Chemistry - Element creation and stars, atoms, fission, fusion, big bang, radiation, chemical reactions, balancing chemical equations, the carbon cycle, global warming	Saturday program- Element creation and stars, atoms, fission, fusion, big bang, radiation, chemical reactions, balancing chemical equations, the carbon cycle, global warming STEM- bioenergy farm game, carbon footprint, duct tape wallets/accessories	SAT Prep, Resume Building, Financial aid resourcing, New Brunswick Farmers Market Volunteering, Mentoring
Eleventh Grade	Physics-Waves, sound, motion	Saturday Program –Waves, sound, motion, SAT prep, college tours, guest speakers STEM- drone discovery activity, bio-degradable fork, hydraulics with syringes	Summer internships/career shadowing, Mentoring
Twelfth Grade	AP Science Courses- Physics, Biology, Chemistry	STEM mini projects (TBD), Applying to colleges, college tours, financial aid resourcing	Summer mentoring with younger NtN students

Figure 1: NtN augmentation and extension of the Public School Science Curriculum

Cognitive Impacts



Non-cognitive Impacts

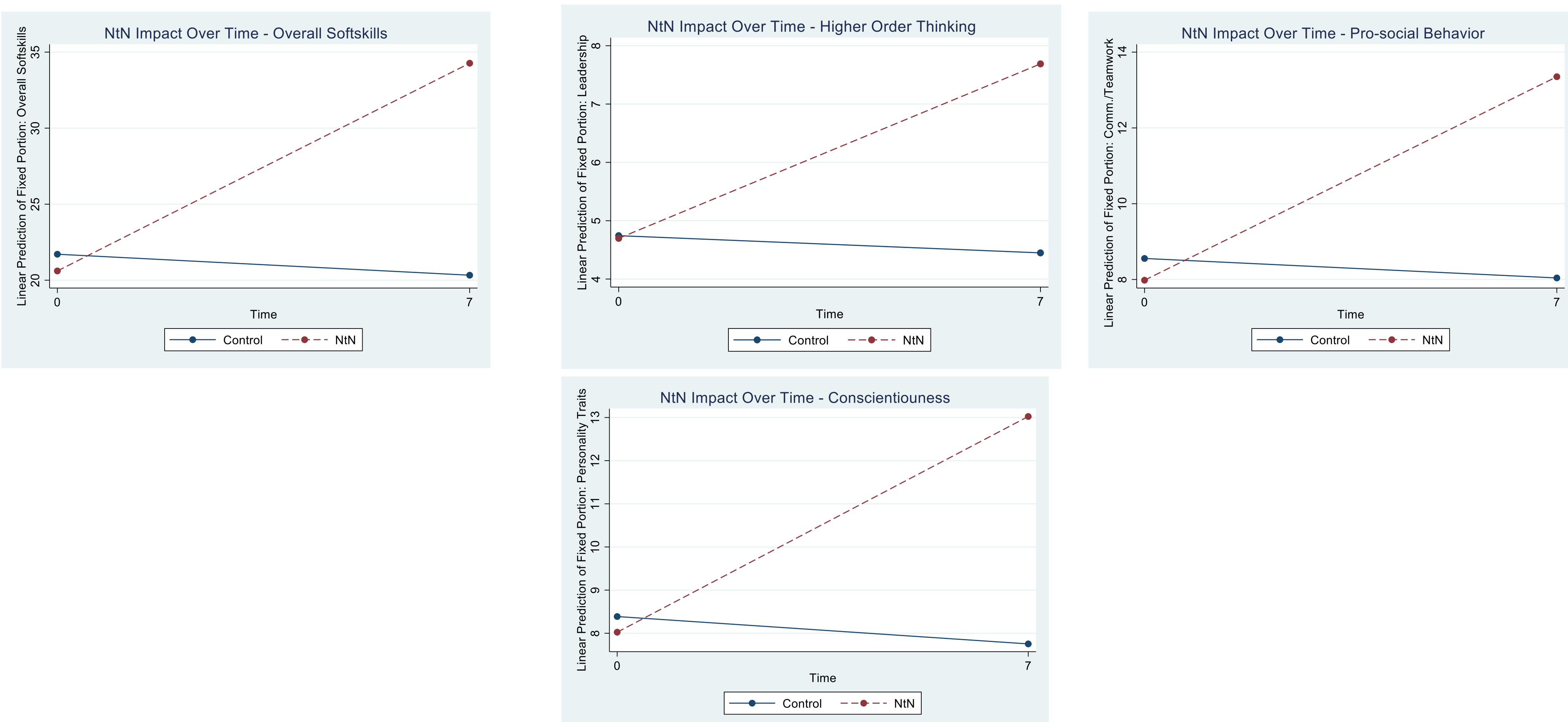


Figure 2: NtN Impact on various outcomes over time

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Dr. Jagannathan is a professor of statistics at the Edward J. Bloustein School of Planning and Public Policy, Rutgers University. She received her Ph.D. from Princeton University. She is a Fulbright Scholar (to Germany, Hungary and Finland) whose research on human capital development, school-to-work transition, poverty, and child welfare has received wide attention. She has received numerous teaching and research excellence awards, and her research has appeared in many economic, education and policy journals such as the *Journal of Labor Economics*, *Journal of Economic Perspectives*, *Economics of Education Review*, *Journal of Policy Analysis and Management, Social Science Quarterly,* and *Evaluation and Program Planning*. She has authored 4 books (Oxford University Press, Bristol University Press) and over 150 journal articles and reports. Radha has evaluated numerous human capital and job training programs run by public, private, and non-profit sectors. She was one of the principal architects of an EU-funded, 11-country youth unemployment study entitled Cultural Pathways to Economic Self-sufficiency (CUPESSE) conducted during 2014-2018. She has co-founded the Nurture thru Nature (NtN) program at Rutgers. At the Bloustein School, Radha teaches courses on statistics, advanced econometrics, and program evaluation.

Dr. Michael J. Camasso is a professor of agricultural and resource economics at the School of Environmental and Biological Sciences, Rutgers University, U.S.A. He received his Ph.D. from Pennsylvania State University. He is a Fulbright scholar, a DAAD Fellow, and the recipient of the Richard W. Laity Academic Leadership Award. He is also the recipient of the Frank R. Breul Memorial Prize and NIMH Award for Promising Scholarship. Michael has written 6 books, over 60 referred journal articles and more than 150 research reports. His research has appeared in many scholarly journals including *Journal of Labor Economics, Contemporary Economic Policy, Research in Labor Economics* and the *Journal of Policy Analysis and Management,* and many others. Michael has discussed his research nationally and internationally in such forums as the Lehrer News Hour, National Public Radio, CNBC, PBS, the New York Times, the Wall Street Journal, the Washington Post, the London Times, and at many national and international conferences. He is the co-founder of the Nurture thru Nature program at Rutgers. His current projects include comparative studies of social and cultural capital across Europe and the United States with a focus on youth. At Rutgers, he teaches courses in econometrics, business statistics, and entrepreneurship.