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Gender-Specific Effects of a Summer Research Program on STEM Research Self-Efficacy

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Gender-Specific Effects of A Summer Research Program on STEM Research Self-Efficacy

1. Background

The concept of self-efficacy is described by Bandura[1,2] as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances". These self-judgments affect a person's willingness to attempt or avoid a related task. Bandura postulated that there are four sources of information that individuals use to develop self-efficacy expectations: (1) performance accomplishments (experiences of success), (2) vicarious learning or modeling, (3) verbal persuasion (encouragement or support), and (4) emotional arousal (anxiety related to the task).

In 1989, Bandura[3] expanded on the theory of self-efficacy to develop the social cognitive theory in which feedback from the social environment is incorporated into the formation of the image of self. Social cognitive career theory[4] describes a process of career choice and path framed by Bandura's social cognitive theory. In this context, "career" includes preparatory activities, including choosing a college major. Lent, *et al.*[4] described three social-cognitive factors that can contribute to career choice: (1) self-efficacy beliefs, (2) outcome expectations, and (3) goal representations. While self-efficacy has not been significantly associated with objective measures of ability,[5,6] it has been found to be significantly associated with or predictive of career and academic field choice and success.[7-9] This disassociation between objectively measured ability in a field and likelihood of pursuit of and accomplishments within that field has been the focus of research on and interventions by the STEM education research community.

Bandura suggested that interventions that increase an individual's feelings of self-efficacy surrounding particular tasks, would, in turn, increase their willingness to attempt these tasks and decrease their level of anxiety surrounding the task. As this relates to the pursuit of a STEM-related career, interventions that enhance STEM or STEM research self-efficacy should have an impact on future STEM career choice. Since STEM careers typically require STEM college degrees, it is necessary to carry out such interventions well before college or the college application process.

Decreased STEM self-efficacy in female high school students may contribute to lower numbers of females in certain STEM majors and subsequent STEM careers. Gender differences in self-efficacy have been demonstrated in relation to math and engineering disciplines among undergraduate students.[10,11] We investigated the effects of a mentored summer research experience on high school students' self-efficacy as it applied to STEM research-related tasks. The program participants are approximately 50% male and 50% female. Participants were asked to answer a 32-item anonymous, online survey, which is designed to measure STEM research self-efficacy, both prior to entering and immediately upon completion of the program.

2. Brief Description of Summer Program

Based at New York University Tandon School of Engineering (NYU Tandon), a formal summer research program, currently in its third year, served promising 10th and 11th grade students from across New York City (NYC). Applied Research Innovations in Science and Engineering (ARISE) is a seven-week summer research program that includes coursework, participation in an ongoing research project in a faculty lab, and mentoring by a graduate student or a postdoctoral researcher. Research in these labs encompasses electrical, mechanical, and civil engineering; information systems and cybersecurity; materials science and robotics; protein engineering and molecular design; evolutionary genomics and proteomics; and bio-interfacial engineering and diagnostics. After an initial online application, lab tours, and interview processes, students and labs were matched to align and maximize interests. Students also received formal college guidance and training in public speaking during the summer. The program ended with a colloquium, open to the university community and family members of students, where participants gave short talks to present their work.

The program includes two courses: Dimensions of Scientific Inquiry (DSI) and Basic Robotics to Inspire Scientific Knowledge (BRISK). DSI, taught by a member of the NYU faculty, is a discussion-based course that covers scientific methods and practice, including their social, cultural, political, and economic contexts; ethical questions surrounding science and technology; and writing, especially as it relates to college application materials and a scientific poster presentation. BRISK, taught by an NYU engineering graduate student, covers data acquisition through the use of LEGO Mindstorms robotics kits and data set manipulation and analysis in Microsoft Excel. These courses each met for two and a half hours per day during the first two weeks of the program.

The Irondale Theater Ensemble provided all students with five, two and a half hour workshops, spread out over four weeks, on improvisation and public speaking techniques to groups of 12 to 13 participants. Skills such as projecting one’s voice, effective body language, and the ability to respond to unexpected questions are covered during group exercises led by acting professionals. Some graduate student mentors also take advantage of Irondale’s offering to hone their presentation skills. The NYU Tandon director of enrollment management, an NYU financial aid officer, and the DSI instructor led one and a half hour sessions of college advisement to groups of 5 to 6 students. The students received feedback on their draft college essays and advice on: choosing a college essay topic, creating a list of candidate schools, interacting with interviewers, and understanding college financial aid terminology and processes.

Each mentor was assigned one to two mentees and a given lab was assigned between two to four mentees. Mentors, typically advanced graduate students or post-doctoral researchers, began contact with their assigned mentee(s) after the completion of the matching process. Participants were invited by mentors to meet in their free time to discuss the research project, ask questions, or receive a more in-depth tour of the lab prior to the official start of the program. Mentors also checked in with participants during the first two weeks of the program before commencing formal research in their assigned lab. The specific schedule and format of the mentored research was generally left up to the faculty and mentor, however, mentors were required to spend a total of 100 hours with their mentee(s) over five weeks and structure their mentee's work such that it took place during the regular workday. Mentors were required to: select a specific project that was part of ongoing research prior to the start of the program, teach their mentee(s) associated lab techniques, and guide participants in the development of a research poster and the associated oral presentation.

2.1. Participant Recruitment

A concerted, targeted marketing effort was made, once the application period opened in mid November 2014, resulting in both a large number of applicants and high proportion of racial and ethnic minorities traditionally underrepresented in STEM (as defined by the National Science Foundation). The program website and application were promoted using a curated email list of over 2,200 contacts in schools, targeted communities, parents, and community organizations as well as a strong social media presence and word of mouth from previous participants. Long-standing relationships with the NYC Department of Education (DoE), teachers, and STEM-related non-governmental organizations allowed for successful recruitment of a large, highly qualified, diverse applicant pool. This resulted in 167 applications from students representing 52 high schools by the end of the application period in early March 2015.

2.2. Application and Selection Process

Participating labs were divided into three broad research categories: Life Sciences, Engineering, and Computer and Data Science and are described in short profiles on the program website. Students were asked to review lab profiles and, on their electronic application, rank the three research categories by level of interest. Approximately half of the applicants were invited to lab tours, at which they visited each lab falling within their top-ranked interests, for 20 minutes, in groups of 8 to 10. Applicants also participated in a group discussion about their STEM interests. Subsequently, using an online form, students ranked labs they toured in order of their interest. Approximately two-thirds of these students were invited for a "speed-dating" style set of interviews with lab members from up to four labs that they ranked. Then, lab members ranked students and students re-ranked labs. This information was used, with an algorithm, to assign two to three students (and two waitlisted alternates) to each lab, to maximize choices of both students and lab members. A total of 38 students were assigned to 16 labs.

The initial applications included approximately 44% females, overall, and this proportion increased slightly for the lab tour and interview steps. However, proportions differed by preference of broad research categories (Table 1). More female applicants listed Life Sciences as their primary preference while more male applicants listed Engineering or Computer and Data Sciences as their primary preference. Attempts were made to increase the proportion of females invited to Engineering or Computer and Data Science lab tours and interviews and to increase the proportion of males invited to Life Sciences lab tours and interviews, to address gender diversity in STEM at the level of research disciplines, however the tour and interview processes ultimately determined lab placements.

Table 1: At a given stage of the application process, for a group of students who had chosen each STEM area as their preference, the % of female students.

% female students at each stage by their top ranked STEM areas

STEM Area	Applicants N=167	Lab Tours N=88	Interviews N=63	Placements N=37
Life Sciences	61%	76%	85%	89%
Engineering	18%	15%	19%	8%
Computer and Data Sciences	42%	45%	50%	50%
Total	44%	50%	54%	54%

2.3. Participants

The program was selective (23% acceptance rate with 38 of 167 applicants accepted in 2015). To provide access and opportunity to a broad demographic, recruitment efforts focused heavily on high-potential high school students who were educationally underserved and/or socioeconomically disadvantaged. Of the 38 accepted students in 2015, 40% self-identified as underrepresented minority (Black/African-American or Hispanic) and 54% were female (Table 2). One student withdrew early in the program due to a family move, resulting in 37 students who completed the program. Based on responses to the pre-program survey, all participants expected to attend college and all but one participant stated that they expected to major in a STEM field while in college.

Table 2: Program participant demographics. Total number of participants self-reporting a given race or ethnicity and percent females within each category.

Participant Demographics		
Self-reported race/ethnicity	N	% female
Asian	13	54%
Black or African American	9	78%
Hispanic or Latino	6	17%
White	6	50%
I choose not to answer	3	100%
Total	37	54%

3. Survey Data

Data were responses to anonymous, online surveys completed prior to and again at the end of the program. Students were emailed a link to the survey after they had accepted their lab placement, but prior to the program's start. At the end of the program, after completing their oral presentations, students were given the link to the anonymous, online survey followed by an email reminder.

Knowledge of the types of skills needed in performing STEM research and several illustrative examples of self-efficacy surveys[12] for diverse domains initially led to the consideration of the following 12 items for the STEM research self-efficacy survey.

1. Identify a research problem
2. Ability to conduct literature search and obtain scientific/technical papers
3. Comprehend scientific/technical papers
4. Pose a research hypothesis
5. Break down a problem into sub-problems
6. Apply math and science skills to solve a research problem
7. Formulate a research plan, design experimental setup or numerical simulation
8. Conduct research, draw conclusions, and document results (figures, tables, plots, images)
9. Ability to learn from past mistakes and avoid future ones
10. Challenging/correcting mentor/peer who may have made a mistake
11. Communicate results to a diverse audience (mentor/peers/family members)
12. Report results in a written report/technical paper

Consultation with research mentors as well as consideration of students' secondary school education level led to the elimination of four items (1, 3, 4, 10) and the rewording of remaining items resulting in the following eight STEM research-related tasks.

Eight STEM Research-related Tasks:

1. Search for and obtain scientific/technical papers
2. Break down a problem into sub-problems
3. Apply math and science skills to solve a research problem
4. Design experimental setup or numerical simulation
5. Conduct research, draw conclusions, and document results (figures, tables, plots, images)
6. Learn from past mistakes and avoid future ones
7. Communicate research results to a diverse audience (mentor/peers/family members)
8. Communicate research results in a written report

Drawing inspiration from an instrument used to measure engineering design self-efficacy,[13] the STEM research self-efficacy survey sought students' response for each of the eight tasks under four categories. Specifically, using a 100-point range on a Likert scale with 10-unit intervals, students were asked to rate their level of confidence, level of motivation, how successful they would be, and degree of worry regarding eight STEM research-related tasks, for a total of 32 items. That is, for each of the four categories (confidence, motivation, success, and worry) the same 8 STEM research-related tasks were presented. In addition, respondents were asked to identify their gender. Data were gathered from 92% (35 of 38) of participants pre-program and 89% (33 of 37) of students post-program.

Four Categories:

1. Rate your level of confidence (belief in your ability) to perform the following tasks: 0 (not at all confident) to 100 (totally confident)
2. Rate how motivated you would be to perform the following tasks: 0 (not at all motivated) to 100 (extraordinarily motivated)
3. Rate how successful you would be in performing the following tasks: 0 (not at all successful) to 100 (I'll ace this)
4. Rate your degree of worry regarding performing the following tasks: 0 (no worries) to 100 (I'm terrified)

Categories 1 and 3 were similar, which helped identify accurate vs. careless or randomly chosen answers. In addition, Category 4 required a reverse rating; again, useful to identify respondents who might answer by checking off all 100s, for example. After removal of such outliers (i.e., same number entered across all items) from the responses, there were 34 pre- (19 Female, 15 Male) and 31 post- (15 Female and 16 Male) responses (Table 3). Pre and post surveys were unmatched.

Table 3: Respondents

	Pre	Post
Female	19	15
Male	15	16
Total	34	31

4. Analysis and Results

Figure 1 provides category means for the four listed categories (averaged across all eight tasks). Moreover, Figures 2—5, are devoted to one category each, providing means for each of the eight tasks individually. The results for females and males are provided on different colored bars and each mean denoting bar also marks one standard deviation statistics. Tables 4 and 5 provide summary analysis of the survey data.

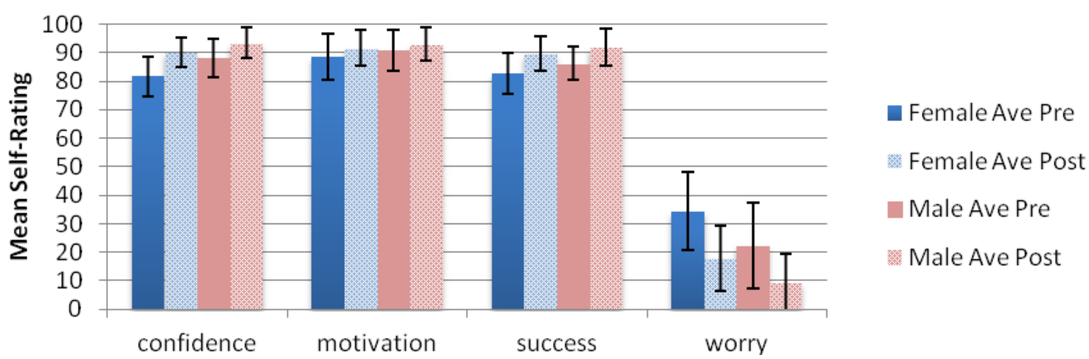

Figure 1: Category mean ratings for eight STEM research-related tasks.

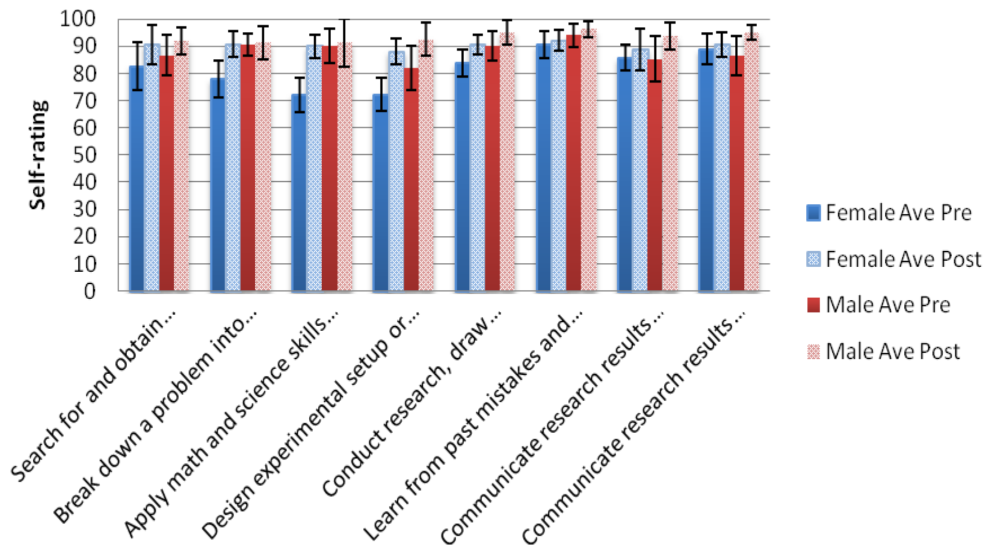

Figure 2: Mean confidence rating for eight STEM research-related tasks.

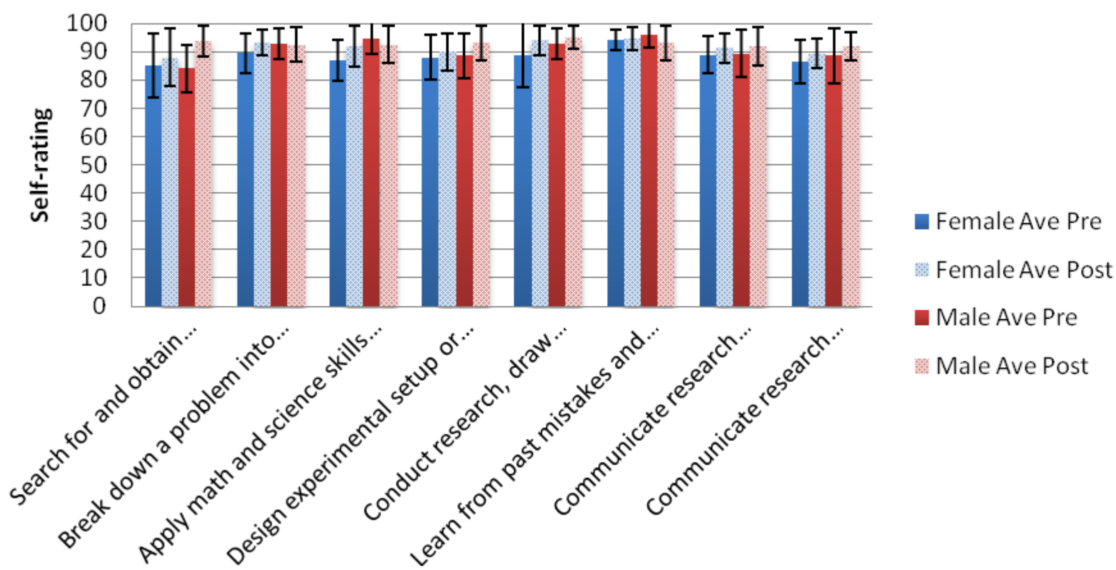

Figure 3: Mean motivation rating for eight STEM research-related tasks.

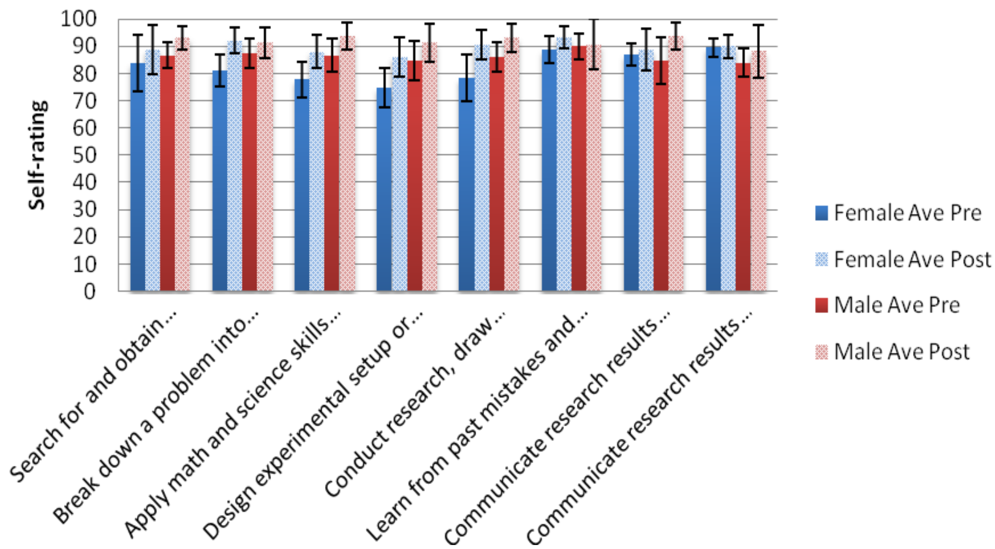

Figure 4: Mean success rating for eight STEM research-related tasks.

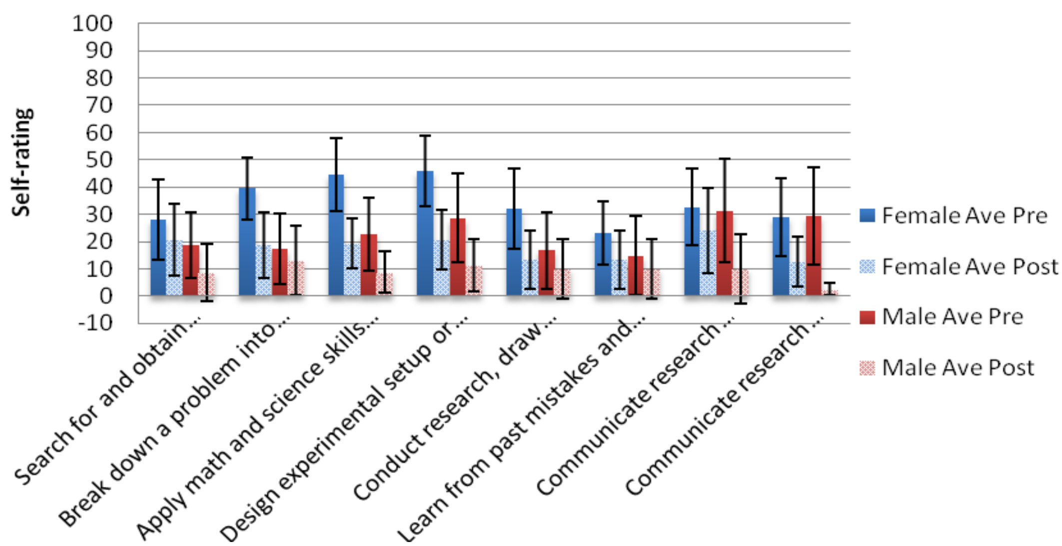

Figure 5: Mean worry rating for eight STEM research-related tasks.

Table 4: Pre- and post-survey mean self-reported levels and change averaged across eight items within each of four categories, by gender.

	Male Average			Female Average		
	Pre	Post	Change Pre to Post	Pre	Post	Change Pre to Post
Confidence	88.17	93.36	+5.19	81.71	90.17	+8.46
Motivation	90.83	92.97	+2.14	88.49	91.58	+3.10
Success	86.25	91.88	+5.63	82.63	89.67	+7.04
Worry	22.42	9.30	-13.12	34.34	17.83	-16.51

Table 5: Gender difference (male minus female) pre versus gender difference post in mean self-reported levels across eight items within each of four categories.

Gender gap (Male Average - Female Average) decreases post program		
Category	Pre	Post
Confidence	6.46	3.19
Motivation	2.35	1.39
Success	3.62	2.21
Worry	-11.93	-8.54

Descriptive statistics suggest that after participation in the summer research program, students' STEM research self-efficacy increased as measured by higher mean self-ratings of confidence, motivation, and success and lower mean self-ratings of worry regarding their abilities to perform STEM research-related tasks (Table 4). While these trends were true, on average, for both male and female students, a pre-program STEM research self-efficacy gender gap (females reporting lower mean self-efficacy than males) narrowed post-program (Table 5). Communication-related tasks showed a reverse pattern: males reported lower self-efficacy pre-program than females for many of these items. Both genders increased in self-efficacy for these tasks, however, increases for males were greater, such that the gender gap widened, post-program for communication-related tasks (see Figures 2—5 and Appendix A).

5. Discussion

Results indicate that, with the exception of tasks related to verbal and written communication, female respondents, on average, had lower pre-program STEM research self-efficacy than male respondents. Post-program, STEM research self-efficacy increased for both males and females and average differences in STEM research self-efficacy decreased between genders. Male STEM research self-efficacy regarding communication tasks increased to the point of surpassing that of females. Both pre- and post-program, females report greater anxiety than males regarding STEM research-related tasks, however, there was a large decrease in female reported anxiety regarding STEM research-related tasks.

These results are notable, considering that all program applicants are likely to have higher than average STEM or STEM research self-efficacy to begin with, in order to complete the rigorous application, lab tours, and interview processes. All program participants have mean GPAs above 90, and have had previous “success” in STEM, if only in the context of school assignments and tests. This is consistent with findings that self-efficacy is not significantly correlated with objective measures of ability and that female students, even those who have self-selected for a STEM major, have lower self-efficacy than males as it applies to their career path.[14] All but one of the participating students asserted, prior to entering the program, that they intend to have a STEM major in college, however, there was still a noticeable change (though statistically not significant) in STEM research self-efficacy measures, and it was possible to see a distinction between genders. Success in STEM-related schoolwork, alone, may not be enough to provide students, especially females, with the ability to envision themselves as STEM professionals. As delineated below, the summer research and mentorship program provides participants with the four sources of information that, according to Bandura, mold self-efficacy and which can be acquired through social interaction in contrast to classroom instruction.

(1) Performance accomplishments, i.e., experiences of successfully performing the behaviors in question – Participants work in a major research university lab on an ongoing, authentic research project. They are considered a lab member; they undergo all required lab safety trainings, operate lab equipment and use lab reagents, are responsible for recording or analyzing data, suggest experiments or changes to an experiment, and are given a University ID with electronic access to their assigned lab.

(2) Vicarious learning or modeling – Students are assigned a graduate student or postdoctoral research mentor who is responsible for a minimum of 100 contact hours with the participant over the summer. In addition to the official mentor and the faculty lab director, the high school students work alongside undergraduate and graduate students, all of whom are pursuing a STEM education.

(3) Verbal persuasion, e.g., encouragement and support from others – Direct contact with mentors and other lab members allows participating high school students to receive daily feedback and provides them with multiple experts to answer questions in real-time. It is typical for lab members to discuss future college plans with their mentees, provide them with career advice, and maintain contact with them while they apply to and enter college. Of participants who filled out the post-program survey, 85% answered that they discussed either with their mentor or other NYU graduate students, where to apply to college and 76% answered that they had also discussed graduate school options. The mentors and other lab members help program participants prepare their final poster and practice their oral presentation.

(4) Emotional arousal, e.g., anxiety, in connection with the behavior – Students, naturally, have some level of anxiety when beginning in a lab; they are afraid that they will break a piece of equipment, waste expensive reagents, or not understand the work. In addition, the program ends with two parallel sessions in which students make an oral presentation of their work in front of approximately 30 students, university faculty, and family members. This presentation must first be written up in the typical form of a scientific conference poster. Mentors assist students in the production of the poster and students receive training in effective communication and public speaking from the Irondale Theater Group. Students end the summer with concrete evidence of their accomplishments, legitimacy as a contributor in a research lab, and have overcome some anxiety related to communicating science verbally, in front of an audience.

6. Conclusions

Three trends emerged from the data. After participation in the high school summer research and mentorship program, both male and female students, on average, gave themselves higher self-ratings of confidence, motivation, and predicted success and lower self-ratings of worry regarding their abilities to perform STEM research-related tasks. A pre-program gender gap in self-ratings (females reporting lower mean STEM research self-efficacy than males) narrowed, post-program. An exception to the overall pattern of higher initial self-ratings among male participants was seen in communication-related tasks, although male mean self-ratings overtook female mean self-ratings in these categories, post-program. Limitations of this study include small sample size and unmatched pre/post samples. In addition, this is not a longitudinal study, so we can not directly assess longer term effects of the STEM research self-efficacy increase, overall, among these students or effects, if any, of the decreased gender gap in STEM research self-efficacy. Although, at present, sample size is too small to test for significance, in future years, additional data will be collected from our own program as well as from several other partner organizations conducting similar summer research programs. Our preliminary results hold implications for the use of summer research programs to (1) improve high school student STEM research self-efficacy in an effort to increase the number and probability of retention of

STEM majors and (2) increase diversity in STEM fields through equalizing STEM research self-efficacy between genders.

Acknowledgements

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Appendix: Male and Female Mean and Standard Deviation for 32 Items, Pre and Post Program.

		Female				Male			
		Pre (N=19)		Post (N=15)		Pre (N=15)		Post (N=16)	
		Average	Std Dev	Average	Std Dev	Average	Std Dev	Average	Std Dev
Rate your level of confidence (belief in your ability) to perform the following tasks:	Search for and obtain scientific/technical papers	82.63	17.90	90.67	14.38	86.67	14.96	91.88	9.81
	Break down a problem into sub-problems	77.89	13.57	90.67	9.61	90.67	7.99	91.25	12.58
	Apply math and science skills to solve a research problem	72.11	12.73	90.00	8.45	90.00	12.54	91.25	17.46
	Design experimental setup or numerical simulation	72.11	12.28	88.00	9.41	82.00	16.12	92.50	12.38
	Conduct research, draw conclusions, and document results (figures, tables, plots, images)	83.68	10.12	90.67	7.04	90.00	10.69	95.00	8.94
	Learn from past mistakes and avoid future ones	90.53	10.26	92.00	7.75	94.00	8.28	96.25	6.19
	Communicate research results to a diverse audience (mentor/peers/family members)	85.79	9.61	88.67	15.52	85.33	16.42	93.75	9.57
	Communicate research results in a written report	88.95	11.00	90.67	8.84	86.67	14.47	95.00	5.16
Rate how motivated you would be to perform the following tasks:	Search for and obtain scientific/technical papers	85.26	22.70	88.00	20.42	84.00	16.39	93.75	10.88
	Break down a problem into sub-problems	89.47	13.93	93.33	9.00	92.67	11.00	92.50	12.38
	Apply math and science skills to solve a research problem	86.84	14.55	92.00	14.24	94.67	11.25	92.50	12.91
	Design experimental setup or numerical simulation	87.89	15.84	90.00	13.09	88.67	15.98	93.13	12.50
	Conduct research, draw conclusions, and document results (figures, tables, plots, images)	88.95	22.83	94.00	10.56	92.67	11.00	95.00	8.16
	Learn from past mistakes and avoid future ones	94.21	6.92	94.67	8.34	96.00	9.10	93.13	12.50
	Communicate research results to a diverse audience (mentor/peers/family members)	88.95	13.29	91.33	10.60	89.33	16.68	91.88	13.28
	Communicate research results in a written report	86.32	15.35	89.33	10.33	88.67	19.59	91.88	9.81
Rate how successful you would be in performing the following tasks:	Search for and obtain scientific/technical papers	83.68	20.60	88.67	18.07	86.67	9.76	93.13	8.73
	Break down a problem into sub-problems	81.05	11.97	92.00	9.41	87.33	11.00	91.25	10.88
	Apply math and science skills to solve a research problem	77.89	13.16	88.00	12.07	86.67	12.34	93.75	10.25
	Design experimental setup or numerical simulation	74.74	14.29	86.00	14.54	84.67	14.07	91.25	13.60
	Conduct research, draw conclusions, and document results (figures, tables, plots, images)	78.42	17.08	90.67	11.00	86.00	10.56	93.13	10.14
	Learn from past mistakes and avoid future ones	88.95	9.94	93.33	8.16	90.00	9.26	90.63	18.43
	Communicate research results to a diverse audience (mentor/peers/family members)	86.84	8.20	88.67	15.52	84.67	17.27	93.75	9.57
	Communicate research results in a written report	89.47	7.05	90.00	8.45	84.00	10.56	88.13	19.40
Rate your degree of worry regarding performing the following tasks:	Search for and obtain scientific/technical papers	27.89	29.36	20.67	26.31	18.67	23.86	8.75	20.94
	Break down a problem into sub-problems	39.47	22.72	18.67	24.16	17.33	25.76	13.13	25.49
	Apply math and science skills to solve a research problem	44.74	26.74	19.33	18.70	22.67	26.58	8.75	15.00
	Design experimental setup or numerical simulation	45.79	25.89	20.67	21.54	28.67	32.92	11.25	18.93
	Conduct research, draw conclusions, and document results (figures, tables, plots, images)	32.11	29.17	13.33	21.60	16.67	28.20	10.00	21.60
	Learn from past mistakes and avoid future ones	23.16	23.58	13.33	21.27	14.67	29.00	10.00	21.60
	Communicate research results to a diverse audience (mentor/peers/family members)	32.63	27.86	24.00	30.89	31.33	37.77	10.00	25.30
	Communicate research results in a written report	28.95	28.26	12.67	18.31	29.33	35.95	2.50	4.47