Northeast Journal of Complex Systems (NEJCS)

Volume 3 | Number 2 Article 2

March 2021

NetSci High: Bringing Agency to Diverse Teens Through the Science of Connected Systems

Stephen M. Uzzo
New York Hall of Science, suzzo@nysci.org

Catherine B. Cramer
Woods Hole Institute, catherine@woodsholeinstitute.org

Hiroki Sayama
Binghamton University, SUNY, sayama@binghamton.edu

Russell Faux
Davis Square Research Associates, russell@davissquare.net

Recommended Citation

Uzzo, Stephen M.; Cramer, Catherine B.; Sayama, Hiroki; and Faux, Russell (2021) "NetSci High: Bringing Agency to Diverse Teens Through the Science of Connected Systems," *Northeast Journal of Complex Systems (NEJCS)*: Vol. 3 : No. 2 , Article 2.
DOI: 10.22191/nejcs/vol3/iss2/2
Available at: https://orb.binghamton.edu/nejcs/vol3/iss2/2

NetSci High: Bringing Agency to Diverse Teens Through the Science of Connected Systems

Stephen Uzzo[1], Catherine Cramer[2], Hiroki Sayama[3], and Russell Faux[4]
[1] New York Hall of Science, Corona, NY, USA
[2] Woods Hole Institute, Woods Hole, MA, USA
[3] Binghamton University, Binghamton, NY, USA
[4] Davis Square Research Associates, LLC, USA
suzzo@nysci.org

Abstract

This paper follows NetSci High, a decade-long initiative to inspire teams of teenage researchers to develop, execute and disseminate original research in network science. The project introduced high school students to the computer-based analysis of networks, and instilled in the participants the habits of mind to deepen inquiry in connected systems and statistics, and to sustain interest in continuing to study and pursue careers in fields involving network analysis. Goals of NetSci High ranged from proximal learning outcomes (e.g., increasing high school student competencies in computing and improving student attitudes toward computing) to highly distal (e.g., preparing students for 21st century science), with an emphasis on doing real-world research into relevant and ambiguous problems through technologically-infused and highly collaborative projects and defending them to a clear (and sometimes potentially intimidating) audience. The cognitive goals of the project covered broad areas including analyzing, synthesizing, and visualizing quantitative data, and understanding modeling and network statistics. Attitudinal outcomes included improving attitudes toward the statistical study of networks, self-efficacy, and a sense of agency for continuing to pursue further involvement in college studies and careers.

1. Introduction

The NetSci High program was a decade-long initiative designed to empower high school student research teams to do original research projects in network science, largely funded by the National Science Foundation. It consisted of 3 parts: a pilot program, a 3-year implementation and several years of extension of the model. It was accomplished through immersion of cohorts of heterogeneous groups of students from underrepresented and under-resourced high schools in a challenging transdisciplinary field of research, providing them with the statistical, analytical, and theoretical foundations and mentorship necessary to develop research questions and carry out new and original research. To validate their experience, participants were provided the opportunity to articulate their work at network science and complexity conferences, and join authentic global communities of science practice.

In all, over 117 high school students, 22 teachers, 33 university professors and researchers, and 21 graduate students participated in NetSci High.

Here we discuss the background theory that supported the approach, how the work progressed and evidence to support the hypothesis that high school students have the intellectual capacity to carry out research in the transdisciplinary domain of network science, that performing such research affects their self-image and agency to ask hard questions and leverage computer-based network analysis tools to answer them, and that it can affect the perception of career choices. We provide details on how the program was conceived, developed, and iteratively evaluated plus artifacts generated by participants through surveys, interviews, reflections and focus groups that were documented by the program team and external evaluator in order to understand the effects on participants.

1.1 Why network science?

Network science, also known as the *science of complex networks*, is the study of complex connected systems. It emerged toward the end of the 20th century from the rapidly increasing power of computers, new computational tools and the availability of vast amounts of structured data across science, medicine and engineering domains. Leveraging techniques that had been used traditionally to graph and analyze social systems to a broad gamut of physical, molecular and biological systems, network science has allowed new areas of research and discovery to emerge, including helping to deepen understanding of topics as disparate as protein interactions, the Internet, sophisticated social systems, the brain, and ecosystems, and is being applied to otherwise intractable engineering and scientific problems [1][2][3][4][5][6]. Because network science was relatively nascent, transdisciplinary, and a field of science with many opportunities for discovery, we felt that it was ripe for a variety of original research projects across many domains of human culture. Additionally, over that same period, interest in and use of social networking and media in teen populations had also increased dramatically [7][8][9]. Suddenly, it seemed, teenagers were very conscious of their relationships within and across these technology-mediated networks, and the structure, strength of ties, vulnerabilities, and evolution of them. We saw this as an indication that there might be interest and opportunity to develop and test new forms of STEM engagement with underserved teens through network science.

2. Pilot Project: A Network Science Research Competition

In 2010 we conceived a year-long intensive project to test our hypothesis that high school students could devise and successfully perform sophisticated network science research. In this pilot project, teams of underserved students conceived of, led and managed the research. We organized it as a poster competition and obtained support for the pilot from the National Science Foundation (NSF). Seven research teams, each including a teacher and between 1 and 4 students in grades 10 and 11 worked with network science researchers and graduate students at Harvard Medical School, Columbia University, Binghamton University, City University of New York, and St. John's University to do a year-long original research project. High school student teams produced posters on a range of research topics. A scientific committee consisting of network science researchers in the U.S. and across Europe reviewed the submitted posters and selected three winning posters: (1) "Does Facebook Friendship Reflect Real Friendship?", (2) "Preaching to The Choir?" and (3) "Using Social Networks to Measure the Success of a Message." The students and teachers of the winning posters were supported to attend the International School and Conference on Network Science (NetSci) in Budapest, Hungary in June, 2011 and presented their posters. Posters from the other 5 teams were also displayed at the poster session of the conference. All student posters were again displayed at the Eighth International Conference on Complex Systems in Boston, Massachusetts in the U.S. in June, 2011[1].

We surveyed and informally interviewed the 25 high school student participants at the end of the experience and there was a consensus (anecdotally) that this year-long intensive network science research project was a life-changing experience for them. This real-world experience had the benefit of galvanizing both the students' understanding of network science and the teachers' understanding of the context of network science as a new kind of research through teamwork, mentorship, and immersing themselves in an authentic research experience at research labs in New York and Boston. Students expressed positive attitudes such as "undeniable feeling of discovery," "fascinating" and "complexity but also freedom," the ability to "think about what would interest us, and not what the school curriculum demanded of us" and "to be a part of something new and different, something I wouldn't have been able to experience in a school classroom." For some students their attitudes toward science was changed through their participation, stating that it "profoundly changed the way I view science"; that it was "an intense experience working with real life samples and research questions" and that "it has piqued my interest in, not only network science, but a science career in general" and "exposed me to a science that I originally never personally considered;" "I will be able to think of a world as a connected place with an algorithm to solve every problem."

Several students indicated that they planned to continue working with network science. They appreciated how the experience gave them an introduction

[1]As of this writing, posters can be accessed here: https://sites.google.com/a/binghamton.edu/netscihigh/year1.

to the real process of science rather than the "scientific method" they were taught in school, and "overall be a better student, listener and worker." They recognized that this also gave them "an advantage for doing a research study during my college career because I will have a knowledge of the process that not many students will," citing both teamwork skills and "overall life skills" such as to "learn to work with students who I did not know and were not in my circle of friends." The experience gave them a sense of belonging: "those of us students who…are fascinated by how things relate to each other and the patterns in connection, may have our place in the scientific community after all."

We also received anecdotal feedback from the participating research labs that indicated the need to support and mentor graduate students, that the high school students and their teachers needed additional computer programming and database skills in order to use the analytical tools necessary for their research projects, and that we should be working to cultivate a community of practice leveraging the momentum building from the NetSci conferences[2], which have global reach.

During the 2011-2012 school year, 2 high school teams from Vestal High School in Binghamton, NY completed year-long research projects and traveled to Northeastern University to defend their work at the NetSci 2012 poster session.

3. A 3-year Implementation: Network Science for the Next Generation

The success of the pilot encouraged us to make changes to the initial design of the program to run 3 yearly cohorts, each including a total of 40 high school sophomores and juniors formed into up to 8 teams, from underrepresented groups (primarily first-generation immigrants, African-American, Latinx and female). Each team would include a high school teacher and graduate student. We would iteratively evaluate and revisit the design each year. Based on the pilot project, we adopted a theoretical framing, which stemmed fundamentally from Social Cognitive Career Theory (SCCT). SCCT is a framework to account for various kinds of personal and environmental influences in career pursuits. It can be used to develop interventions to affect self-efficacy and career outcomes [10]. SCCT has been used in studies with ethnically diverse students and shows that self-efficacy, beliefs and outcome expectations consistently predict choice of STEM majors, persistence, and perceived career options [11]. "The three C's of retention factors" for SCCT are: *contextual*, which refers to how students experience their environment; *cognitive*, which refers to students' perceptions of their capacity to succeed academically; and *cultural*, which includes the effects associated with racial/ethnic or gender membership [12][13].

---

[2] https://netscisociety.net/events/netsci

The intent was for NetSci High to capture the “3 C’s” in the program design and determine what effect on underrepresented students’ attitudes, self-image and career interests would be as a consequence of an immersive, well-mentored year-long program of team research in which participants were trained in the fundamentals of network theory, had to devise a research question, figure out how to address it, and defend their findings among a community of professional network scientists. Authenticity was of the utmost importance in providing opportunities for students to self-generate the purpose and motivation to execute the very ambitious research projects they proposed. In other words, to have the agency to carry out the work, overcome barriers inherent in research activities, succeed at completing the research, and draw conclusions about their findings. The authenticity of the work lies in encouraging them to form goals around the agency they gain from the experience and the self-efficacy they gain from significant supports the experience provides as they transition to being part of a community of researchers.

To provide the level of support that the pilot indicated, we modeled the program on *cognitive apprenticeships* [14][15], in which conceptual and factual knowledge is learned in the context of using computational tools to solve research problems. Through cognitive apprenticeships, students are mentored to: (1) carry out real tasks in the real world, (2) work in a dynamic social setting that is cooperative, (3) choose tasks and set personal and group goals that are considered important or intrinsically interesting, and (4) receive guidance from layers of mentors (in this case: graduate students, teacher mentors, undergraduate volunteers, parents/guardians, and project staff). This framing aligns with constructionist approaches such as, activities are generative, important and meaningful to the students, well mentored and supported [16], with the added motivational benefit of all teams providing authentic contributions of new research to the body of knowledge in network science. In short: “it takes a village.” One of the NetSci High teams published their findings in a peer reviewed journal [17], and teams were given the opportunity each year of the project to defend and explain their work to practicing scientists at a professional science conference.

We again got support from NSF to implement the program. Our primary collaborator was Boston University (BU), which provided classroom and computer lab facilities and access to the network science resources and researchers in the Boston area. Over the 3-year period, additional partners were brought into the program, including Stevens Institute of Technology, Cisco Systems and the Network Science Center at U.S. Military Academy at West Point. Each cohort attended a two-week summer intensive workshop at BU to cultivate the creative and exploratory abilities in participants that are essential in every scientific endeavor, which, while they are not effectively taught in formal educational settings, would be needed to do authentic science work, including:

1. *Data collection and processing*: scientific literature review, data retrieval, cleaning, conversion, importing, matrixing, and filtering;
2. *Data visualization and analysis*: graphing and statistics, classifying and measuring properties;
3. *Pattern discovery*: inductive reasoning, correlation, linear/nonlinear model fitting, clustering and community detection;
4. *Hypothesis generation*: abductive and deductive reasoning, developing multiple explanations for discovered patterns, making predictions, assessing and comparing plausibility of hypotheses;
5. *Research design*: developing answerable, relevant research questions, identifying variables, designing research protocols (experimental or analytical), choosing research methods, human subject protection, ethical issues in scientific research;
6. *Research implementation*: conducting experiment/analysis, data management, lab note taking, evaluating results and re-designing research protocols; and
7. *Scientific communication and presentation*: logical writing, referencing, visual data presentation, creating presentation slide decks, creating posters, oral presentation, communication with a given audience and storytelling.

Computational skills were learned in the summer intensive workshops through talks and hands-on activities at BU, as well as significant extra help in evening group and individual mentoring at The Treehouse (summer residences and collaborative study and studio spaces for participants at the Massachusetts College of Art and Design), and all in the service of developing and executing projects including configuring and programming in Python and NetworkX, NetLogo, Gephi, D3.js; database and matrix development; and how to navigate command line programming; along with teamwork, network challenges and creative exercises. Students were also given extra lab time, talks and mentorship by network scientists available in the Boston area. Every level of training and mentorship took place in the context of actual and meaningful use. The goal at the end of the summer was for each team to have an agreed upon research question and plan for conducting the research during the school year. A workshop manual and resources are available at BU's website.[3]

Summer intensive workshops were followed by the school-year-long team research project at their home schools based on research questions developed during the summer. Field trips to research labs and tech companies were part of the experience. Toward the end of each school year, cohort members completed their research and authored posters to present at conferences. Posters were presented by students at a NetSci High conference at BU at the end of the 2013 school year and

[3] http://www.bu.edu/networks/resources/workshop/

their posters were shown by program organizers at NetSci 2013 at the Technical University of Denmark. The following year student teams attended NetSci 2014 at the University of California at Berkeley to defend their posters. We then held a capstone exposition for all research teams at the 6th International Workshop on Complex Networks (CompleNet 2015) at the New York Hall of Science in New York City[4]. The following is a sample of the projects completed by the NetSci High students, with the projects organized into broad categories[5]:

Games:

- Interactive Simulations and Games for Teaching about Networks
- An Analysis of the Networks of Product Creation and Trading in the Virtual Economy of Team Fortress 2

Medicine:

- Mapping Protein Networks in Three Dimensions
- Comparing Two Human Disease Networks: Gene-Based and Symptom-Based Perspectives
- Quantifying Similarity of Benign and Oncogenic Viral Proteins Using Amino Acid Sequence
- Protein association and nucleotide sequence similarities among human alpha-papillomaviruses
- Similarities found in neurological disorders based on mutated genes and drug molecules

Student life:

- Main and North Campus: Are We Really Connected?
- High School Communication: Electronic or Face-to-Face?
- Relationships between the musculoskeletal system & high school students' sports injuries

Humanities and social science

- A Network Analysis of Foreign Aid Based on Bias of Political Ideologies
- Influence at the 1787 Constitutional Convention
- Quantification of Character and Plot in Contemporary Fiction
- The relationships of international superpowers

Social media:

- RedNet: A Different Perspective of Reddit
- Tracking Tweets for the Superbowl
- How Does One Become Successful on Reddit.com?

Even a cursory glance at the rich variety of student work offers some indication of the sophisticated perspectives that participant teams brought to their

[4] http://2015.complenet.org/CompleNet_2015/Home.html

[5] More information on student projects can be found on the NetSci High website: https://sites.google.com/a/binghamton.edu/netscihigh/.

work, whether the topic be arcane and technical or one that is of an apparent simplicity. During the course of the program each research team set their own goals, which were assessed using feedback relating to our original SCCT theoretical framing of the program. We considered how students experience the environment we created for them through the various events that took place during their participation in the project, including:

Contextual the 2-week summer intensive workshop, research, activities on campus, talks, mentorship, and field trips, as well as work in labs, talks, and research experience during the school year, and finally the effect of the science workshop environment and their experience in creating and defending their posters among graduate students and working scientists;

Cognitive the team's ability to collaborate, overcome adversity, troubleshoot problems, support each other, and judge when to ask for help; and

Cultural the ability to navigate culture, language, gender and ethnicity in both homogeneous and heterogeneous groups while acknowledging the funds of knowledge all participants bring to the discourse.

3.1 Evaluation

The formative and summative assessment of this three-year project was led by co-author Russell Faux from Davis Square Associates and included observations, surveys and focus groups. Ninety-five high school students from 8 different schools along with 12 teachers and 9 faculty mentors from 6 universities participated in the evaluation activities. Synthesizing the many project goals into one rather broad cognitive and one attitudinal outcome, the guiding research questions across all 3 years of the project were:

- *What is the effect of participation on the students' understanding of networks and their skills at analyzing networks?*
- *How does participation in NetSci High affect the students' attitudes toward their own self-efficacy in computational approaches to networks and their commitments to continue to study networks in college and beyond?*

The sample for this study includes all participating students (*N*=95) and teachers (*N*=12) from 8 different high schools, and nine faculty mentors from Harvard University, Binghamton University, Boston University, Columbia University, Stevens Institute of Technology, and U.S. Military Academy at West Point. Here we describe formative data by year then summative from the end of the program. Approaches differed year to year depending on the format of the activities (see Table 1).

Table 1: Overview of data gathering activities over the 3-year period. There was no intentional to compare cohorts but to identify evidence of the effect of the environment (both the physical and social), capacity to succeed and effects of race, ethnicity and gender on collaboration, coherence of the group and peer support.

Cohort	Qualitative	Quantitative	SNA
2012-13	End of summer focus group	End of summer survey	End of summer survey
2013-14	Mid-year survey open questions	Mid-year survey	
2014-15	End of summer focus group; open-ended questions on March 2015 survey	End of summer survey; March 2015 survey	

For Cohort 1, a retrospective pre-post survey used 3 constructs to identify impact of the program on student teams. These constructs were pre-post effects on (1*) the understanding of networks*, (2) *effects on the students' self-efficacy*, and (3) *the social network created among the participants themselves*. All scaled items used a 6-point Likert scale (negative to positive), with the students' experiences receiving further exploration in a 30-minute focus group. Quantitative data were checked for reliability then analyzed in R, with the network data examined in UCINet, while the qualitative data were analyzed in NVivo, using a modified grounded theory approach.

The first section of the survey used 11 retrospective pre-test items (maximum value = 66) to determine the change in student understanding of networks. The pre-post differences were significant ($p<.05$, paired samples t-test) with all items aggregated, with a large effect size of 6.36 (Cohen's d [18]). It is probable that this effect size is somewhat inflated (10-20%) due to the social desirability bias that is inherent in the retrospective pre-test design, however, even when taking this into account, the first summer intensive workshop was an enormous success. The substantial gains speak to both the innovative nature of the summer intensive workshop content and the effectiveness of project activities.

For affective outcomes of increased self-efficacy in networks (Construct 2), the aggregated eight paired items survey again showed the pre-post differences to be both significant ($p<.05$, paired samples t-test) and of a very large magnitude (4.43, Cohen's d). The maximum value for the aggregated items was 48.

For the 3rd construct, students were asked to rate their level of collaboration with the other students over the week of the summer intensive workshop. These questions used a 1-5 scale (1="I don't know who this is" and 5="A very good level of collaboration"). The overall density of the student network was 2.47, fairly high for this kind of network, given that the students were coming from 4 different schools and had little time to develop relationships before responding to the survey.

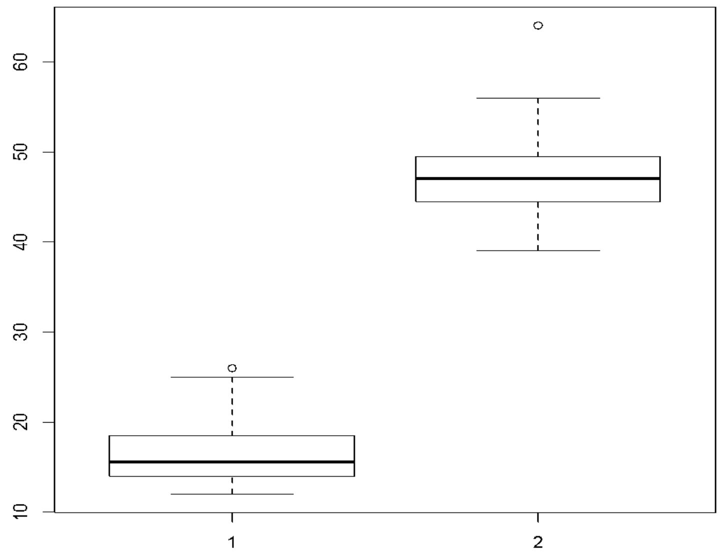

Figure 1. Cohort 1: Pre-Post Learning Gains. The following boxplots show the Time 1 and Time 2 distributions for Construct 1. Note the sharp increase, very small range, and compressed boxes, indicating a small standard deviation and by inference, a general consistency in the project effects.

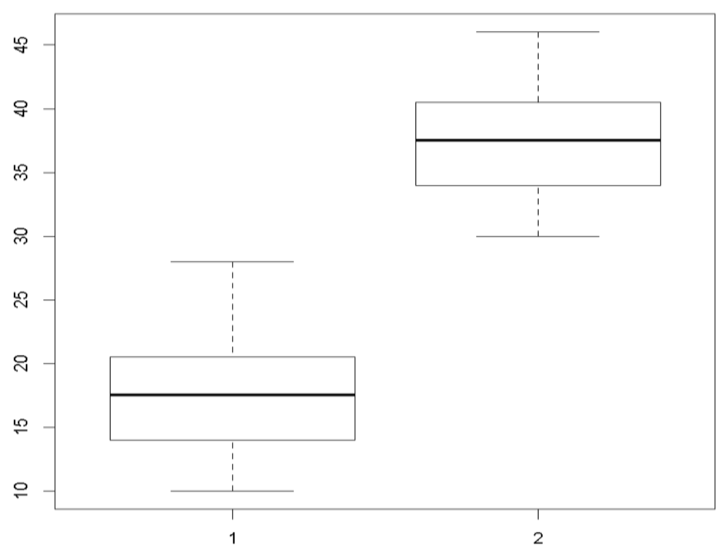

Figure 2: Cohort 1: Pre-Post Self-Efficacy Gains. This pair of boxplots show the Time 1 and Time 2 distributions for the self-efficacy construct. Again, one will readily see the striking improvements, though the variation in the observed values is somewhat larger than seen in Figure 1.

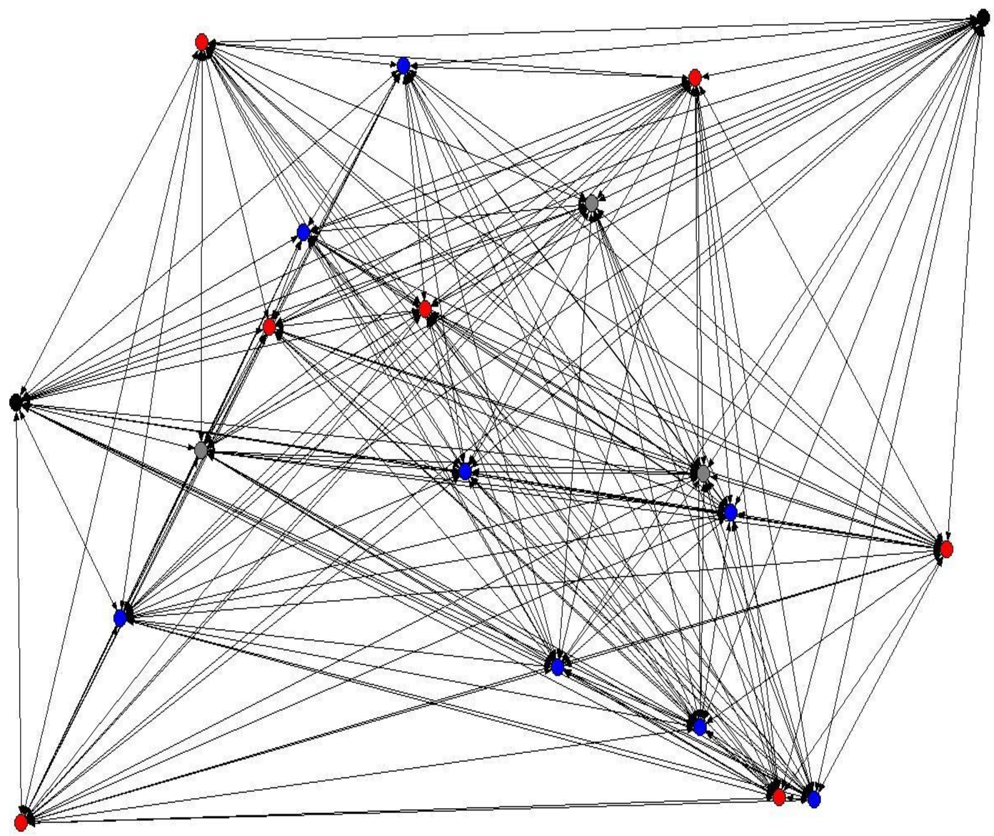

Figure 3: Cohort 1: Collaborative Structure. The network graph shows the students with nodes colored by school (Andover = gray; Binghamton = black; BU Academy = red; Newburgh = blue). Note the lack of clustering showing that students indicated they collaborated more across than within schools during the summer intensive workshop.

The tests for gender homophily showed an E-I index of 0.0, meaning that boys and girls collaborated evenly in terms of the gender of their peers, while the E-I index for schools was a positive 0.2, meaning that students tended to collaborate somewhat more with students from schools other than their own.

There were no significant differences [19] between the four school groups in terms of any centrality measure (in-degree, out-degree, eigenvector, etc.) or ego network measure (size, density, etc.). Further, a K-core analysis placed all actors in a single component, indicating the very low level of sub-group clusterings. Overall, this is a remarkably cohesive network, and a distinct testament to the effectiveness of the summer intensive workshop at quickly building a collaborative social environment.

The focus group following the summer intensive workshop in 2012 explored the major themes of the experience. Data collected (transcriptions of audio recordings analyzed in NVivo) included the students' expectations (retrospectively) prior to the summer intensive workshop and the effects of their participation afterward. Prior to the experience students indicated that they would have benefitted from having information about the program earlier in the school year and would have liked there to be more opportunity to ask questions and follow up with teachers before school ended (before the summer intensive workshop). Further, they indicated that the orientation that happened on the first day of the summer intensive workshop could have happened before the end of the school year so they would have known more about what to expect when they got to BU in the summer. They felt that it would have made the first few days of the summer intensive workshop run smoother for them, but that it was really interesting and a great experience. At the end of the experience, participants indicated that they appreciated the way that networks were contextualized across domains. But they indicated that they would have benefitted from having the summer experience last for a longer period of time.

Surveys for the 2nd cohort failed to provide adequate data due to a technical problem that delinked responses to respondent identifiers, and along with low response rate would not be useful for comparison with the first cohort. To offset this failure a mid-year survey was conducted in January of 2014. It covered much of the same ground as the survey conducted for Cohort 1 with the addition of a series of questions around the enduring effects of the summer work and student project team functioning. The four constructs include: (1) *The value of the summer intensive workshop content for ongoing study*, (2) *The students' confidence levels regarding their projects,* (3) *The frequency with which they met with one another on their teams and with advisors*, and (4) *The value of the social connections formed through participation in NetSci High.*

For the first construct (Ongoing Value) the students were asked a series of fifteen questions about different aspects of the summer intensive workshop at BU. The mean value for each of the six participating schools' students were summed and ordered in the following table. Note that the more general or somewhat abstract content is reported as having greater value than the narrower, more skill-based content. However, as will be seen when the qualitative data are discussed, it is not so much that the skills had little value themselves, but that the students felt they should have received a greater emphasis during the summer. All items showed statistically significant distributions ($p<.05$, Kolmogorov-Smirnov [20][21]), indicating a very strong consensus around the mean values, and there were no significant ($p<.05$, Kruskal-Wallis) differences between schools.

The students were asked how their summer preparation might have been improved (*"Thinking back to the summer, what would have been more valuable in terms of preparing you for what you are encountering now on your project?"*). The responses show a strong and consistent emphasis on the value of more skills training (especially in Python, and, to a lesser extent, Gephi). From the survey and open-ended responses, we infer that the students found the more theoretical aspects of the summer to be valuable in their thinking about their projects, but the more technical aspects of conducting their research were proving to present challenges. We speculate that the value of theoretical insights has a way of enduring (perhaps because it is less often subjected to practical challenges), while the more technical aspects of research are under constant pressure and often the source of some anxiety. For the students to report, therefore, that they continued to value the more general ideas about networks, while at the same time to lament their skills in R or Python, expresses a foreseeable and probably beneficial effect.

Table 2: Cohort 2: Value of Each Activity to Helping with Projects, Aggregated by School. Students believed more technical training was needed to prepare them for the research they were planning on during the school year. Note that all cohort members participated in all activities together.

Item	**Summed M**
General ideas about networks	14.53
How networks are modeled	14.40
How networks are studied	13.90
How information flows in a network	13.63
The themes presented by the guest speakers	13.30
General process of scientific research	12.97
How to visualize/analyze networks using Gephi	12.34
The themes presented by the guest speakers	12.17
Programming in Python	11.87
How to run simulations in Python	11.47
How to visualize networks in Python	11.33
Using NetLogo	10.13
Using NetAttack	9.97
Using NetOpt	9.62
Using GraphR	8.77

For the second construct (Confidence) the students expressed a great deal of confidence in their team's capacity to work together effectively, to find the necessary resources, and for each student to make meaningful contributions to the project. The summed means seen in the "Total" line below represent nearly 80% of the maximum possible value, a striking result. Once again, all items showed statistically significant distributions ($p<.05$, Kolmogorov-Smirnov), indicating a very strong consensus around the mean values.

Table 3: Cohort 2: Confidence in Collaboration, Aggregated by School. Students scored high, believing they worked together well and got support they needed as indicated here.

Item	**Summed M**
Your team's receiving adequate guidance?	15.32
The likelihood of your team completing its project?	15.16
Your team's ability to work together?	15.16
The final quality your team's project will turn out to be?	15.16
Your team's ability to problem-solve effectively?	14.66
The importance of your contribution to your team?	14.87
Your ability to contribute to your team?	14.37
Your team's ability to find the resources it needs?	13.87
Total (max=128)	102.09

For meeting frequency, students reported meeting consistently, though there may be some evidence of group decisions being made without a full participation of all members. The value for the last item has been reversed, with this "polarity reversal" intended to serve as a kind of check on respondent acquiescence. As with the previous constructs, all items showed statistically significant distributions (p<.05, Kolmogorov-Smirnov), indicating a very strong consensus around the mean values.

Table 4: Cohort 2: Meeting Frequency, Aggregated by School. Students indicated that they had sufficient meeting time, although there is some indication that there was some inconsistency in attendance of all team members.

Item	**Summed M**
How frequently has your team met?	13.94
How frequently has the planning for meetings been shared?	13.77
How frequently has important information been shared among team members?	13.68
How frequently does your team come to a consensus before going forward?	11.76
How frequently are you able to draw on outside resources for your project?	11.84
How frequently does your team make decisions without a complete discussion	8.24

When asked about the value of their meetings on the project outside their team, students reported regular within-school connections, supplemented by much less frequent outside-school communications. There were no significant (p<.05, Kruskal-Wallis) between-school differences.

Table 5: Cohort 2: Meeting Value (communication with others), Aggregated by School. Students placed value on their meeting time and met more consistently with their teams than outside of their teams.

Item	Summed M
How valuable have the team meetings been for completing your project?	14.23
How frequently do you draw upon help from teachers or mentors for your project?	14.12
How often have you communicated with other NetSci participants outside your team?	12.19
How valuable have the communications been with others outside your team?	10.67
How often have you communicated with NetSci participants outside your school?	7.80

In summary, students continued to value the theoretical perspectives gained in the summer intensive workshop, that they wished their technical skills were better, that they met and communicated with team members on a regular basis, and that they were confident that their projects would be successful. The variations observed between schools were minimal, and there is every reason to infer that the mentoring the students were receiving was helpful. In other words, the second cohort appeared to be making very solid progress in their projects and the social and intellectual learning needed to see the projects through to completion.

The evaluation of the project effects for Cohort 3 included a very large focus group conducted at the conclusion of the BU summer intensive workshop (2014), a short online survey administered in September, and finally a paper survey in March 2015 during the capstone event that was part of the 6th International Conference on Complex Networks (CompleNet 2015) hosted by the New York Hall of Science[6]. The focus group included all student participants in the 2014 summer intensive workshop, as well as several students from the previous cohort, who were serving as student mentors to the incoming cohort. It was recorded, transcribed, and analyzed using NVivo. While we can make no claims regarding the distributions of any of the themes touched upon in the focus group, the identified motifs in student dialog are helpful in understanding what the experience meant for the participating students. Findings of the summer 2014 focus group were synthesized into three general categories: (1) Academic Content, (2) Affective & Social Context, and (3) Confidence in Project Success.

[6] http://2015.complenet.org/

Table 6: Cohort 3: Focus Group Summary. Students reported positive and optimistic value in all 3 categories (academic content, affective & social context, and confidence in project success).

Domain	Finding	Examples
Academic Context	Students reported the practical value of learning about doing research and gaining new theoretical understandings and practical skills.	*I really like how there is like a very open and creative thought. It is structured but it is not like school* [where] *you are taught to do things one way and that way only but here you can basically do it like yourself.* *It gave me a real-life perspective of how people program in real life, like what tools they use, how they plan their project and collaborate. It is more than just learning programming in the classroom; it is real life.*
Affective & Social Context	Students appreciated the value of extending their social links to include research professionals and reported increases in self-confidence.	*I feel like very empowered to do this science feel like after this whole 10 days I feel like I can do anything.* *I'd like to appreciate the fact that we were allowed to see professors. I think that was really great for us and I think that should definitely be continued.* *That definitely helps you develop speaking tools.*
Confidence in Project Success	Students were sanguine regarding the prospects for their projects.	*I mean like this was just like a 9-, 10-day thing and throughout the year we will learn more and more about programming.* *I don't think I have ever learned so much in a small amount of time. Like after we were done I was so proud of my work.*

The students were asked to complete a short survey in September 2014, about a month after the conclusion of the summer experience at BU (response rate = 85%). Most of the survey was constituted by 19 paired retrospective pre-test items (with 6-point Likert scales), all of which showed significant Wilcoxon gains [22] as well as very large effect sizes (Cohen's *d*). The pre-post change is likely somewhat inflated due to the social desirability bias inherent in this design. Given the very good reliability of the instrument (Cronbach Alpha=0.903 [23]), however, we believe that the data provide further indication of the very strong gains overall made by the students, as well as the relative differences between the items.

Table 7: Cohort 3: Survey Results by Item. The significant pre-post effects indicate that while the pre-survey was retrospective, the gains and effect size is valid and significant.

Item	**M: Pre**	**M: Post**	**Effect Size**
How networks are modeled	1.38	5.19	5.92
Your ability to explain what network science is about to someone with little knowledge of network science	1.88	5.56	5.14
Programming in Python	1.06	4.13	5.07
Using NetAttack	1.13	4.27	4.69
How to visualize networks in Python	1.06	4.25	4.59
Your ability to learn the technologies used in network science	1.69	4.88	4.59
Using GraphR	1.13	3.47	4.41
Research topics introduced by guest speakers	1.63	4.88	4.32
How networks are studied	1.56	5.06	4.29
Your ability to develop research questions in network science	1.69	5.19	4.29
Using NetLogo	1.13	4.00	4.25
How information flows in a network	1.81	5.19	4.16
Your skills at solving at network science problems	1.69	4.81	4.06
Using NetOpt	1.19	4.25	3.50
Your enthusiasm for working in network science	2.20	5.47	3.49
General ideas about networks	2.06	5.06	3.35
Your ability to learn the concepts that are most fundamental to network science	2.19	5.19	3.35
Your ability to design a high-quality research project in network science	2.25	4.81	3.14
Your ability to contribute to a high-functioning network science research team	2.63	5.25	2.55

The mean values for the summed items moved from 31.93 on the pre-test to 89.64 on the post-test, an enormous gain. The following density plots show the distributions for the pre- and post-test moments, and then for the overall gain (post − pre).

When asked about the "biggest positives" of the summer experience, the students touched upon themes presented above in the discussion of the focus group data. The social theme tended to be cited as primary, followed by the more personal theme of individual learning.

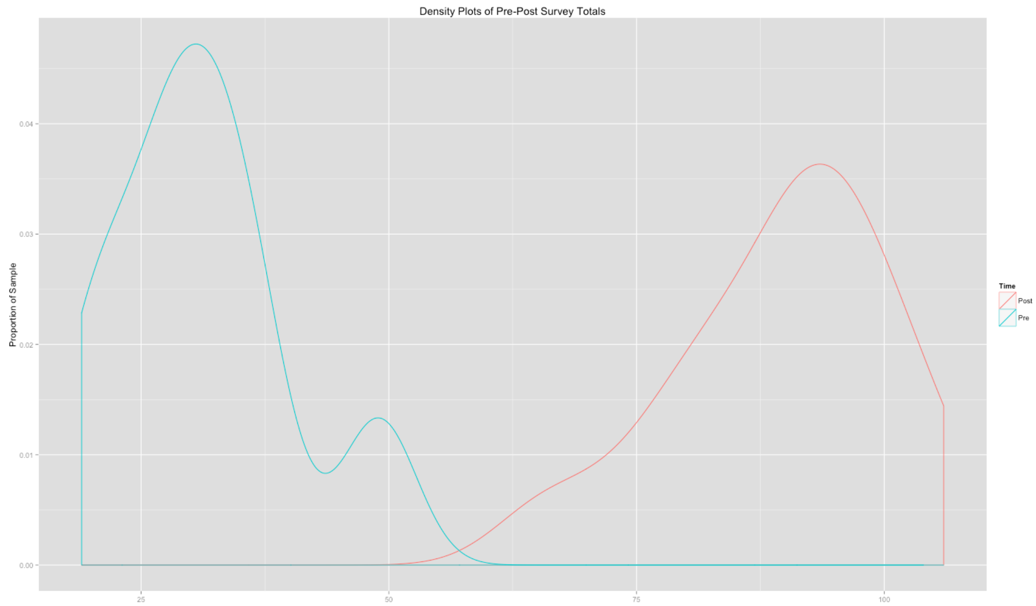

Figure 4: Cohort 3: Summed Pre-Post Survey Items. In this density plot, green is pre-survey (retrospective) and red is post.

Table 8: Cohort 3: Open-Ended Response Sample. Student responses indicated social aspects were of primary importance.

Social/Interpersonal	**Network Skills**
• *I got to meet new people* • *The biggest positives were being able to interact with people that dealt specifically with networks.* • *I liked how a group of creative yet rational students are able to come together to learn and share knowledge about a new field with many opportunities.* • *Getting to study at a college and learning but not feeling the pressure like in school.*	• *I learned more about network science. and how it could be applied to real life situations.* • *Learning about programming and network science.* • *Getting to present my yearlong project.* • *Networks show you a whole new way of looking at sets of data and the world. We were given the chance to learn about many networking programs.* • *The whole program was a new thing that I had never experienced before.*

In concluding the survey, the students were asked for any further comments. The very positive tone of the following offers some insight into the enthusiasm of the students for the NetSci High experience.

- *More time in Boston for more workshops to get a better understanding of Python and the other computer programs.*
- *This program was simply spectacular.*
- *I feel that this program MUST be available for other students in future years. This program and the way it is taught was inspiring to me and can do the same for others. I also feel that there should be more programs like this available for other areas of science, such as biology, physics, and chemistry. Finally, in order to save money for the program, I feel that such a high stipend is not really necessary ($250 for summer work, $500 for school-year research). Don't get me wrong, it's nice to get paid for doing something you enjoy anyway, but the money could go towards other areas of the program (getting computers, paying for network science apps, etc.). All in all, this is an incredible program and I am so glad I chose to attend.*
- *This program is a wonderful program. And I hope it continues for the coming years.*

The final NetSci High evaluation activity was conducted at the New York Hall of Science in March of 2015. Students and their teachers from all years of the program were asked to complete separate surveys. The student survey was completed by 33 students from five high schools and two other students currently in post-secondary programs. The student survey was intended to gather information on four pre-post constructs, namely knowledge of networks, intentions to continue studying networks, attitudes toward network science in general, and frequency of communications about networks. It used 27 retrospective pre-test items and an open-ended question, with the data gathered on paper and entered into SPSS for analysis in SPSS and R. The reliability value of the survey was again very high (0.924, Cronbach's Alpha), indicating the instrument worked well. The teacher survey used three open-ended questions gathered on paper and transcribed.

Students reported large pre-post gains, especially in the areas of knowledge of network science and attitudes toward the study of networks. The effect sizes are very large, though somewhat inflated (up to 15%) due to a social desirability bias associable with the retrospective pre-test design of the survey.

None of the four constructs (knowledge, intentions, attitudes, communications) showed gain scores that were significantly clustered around the mean (p<.05, Kolmogorov-Smirnov). What this means is that some students gained more and others gained less, as could perhaps be inferred from the large standard deviations above. The same observation held true for the aggregated pre-post gain scores. The density plot in Figure 6 shows the very stark shift from the pre-test to the post-test moments.

Table 9: Cohort 3: Final Survey Results. All pre-post differences significant at *p*<.05 (paired samples t test). Lack of clustering (large standard deviation) indicates that there was variability in how much students gained.

Construct*	**M**	**SD**	**Effect Size (Cohen's *d*)**
Knowledge: Pre (max=42)	10.82	4.48	
Knowledge: Post (max=42)	31.82	5.02	4.58
Intentions: Pre (max=48)	12.46	5.81	
Intentions: Post (max=48)	32.11	7.67	3.71
Attitudes: Pre (max=42)	13.51	7.18	
Attitudes: Post (max=42)	31.94	5.92	4.18
Communications: Pre (max=30)	13.41	5.33	
Communications: Post (max=30)	24.71	4.84	2.39
Pre: TOTAL (max=162)	49.51	17.55	
Post: TOTAL (max=162)	118.97	20.48	4.37

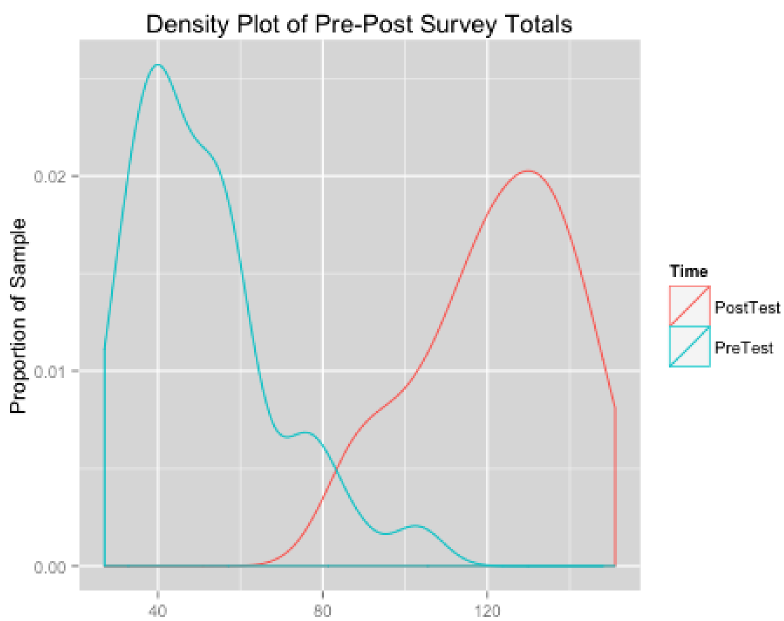

Figure 5: Cohort 3 Pre-Post Density Plots. Shows significant shift from pre- to post-test moments.

Pre-test scores were not predictive of the post-test scores. This is a good finding in that it suggests that the project worked comparably well with students no matter what their levels of preparation at the beginning of their participation. The gray areas in the following express the confidence interval.

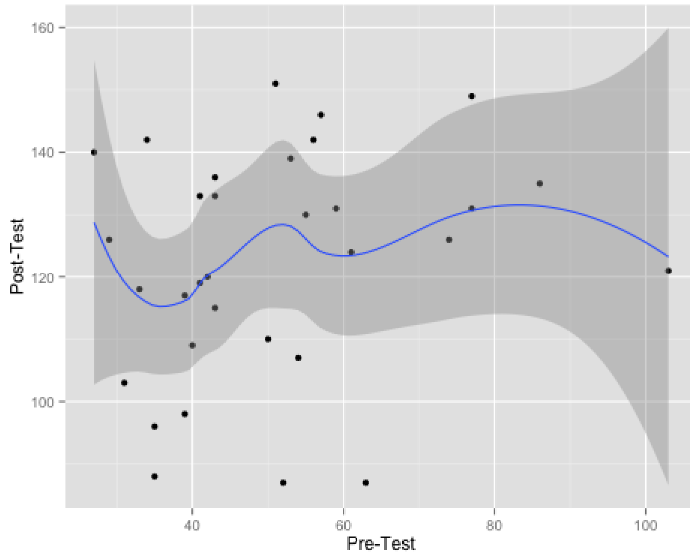

Figure 6: Cohort 3: Post-Test by Pre-Test Distributions. Indicates program effectiveness across heterogeneous group of students. Gray shading shows confidence interval.

Responses to the concluding survey question (*"Finally we would like you to add some thoughts about what participating in this project has meant to you. How do you think you have changed as a result of the NetSci High experience? How has participation affected your plans for the future?"*) split out into the four categories shown below. They provide some structured insight into the very positive tone of the language and the widely varying thoughts of participating students:

i. General changes in perspective:

- *I think that net science will expand humankind's potential at working with data, and since the amount of data will only increase, network science gives us tools for the next generations to come.*
- *NetSci High has allowed me to see the world a different and better way. I can comprehend easier and relate complicated things to networks in order to understand them, i.e., in my anatomy and physiology class. I view the human body as a network of networks and it helps me to learn better.*
- *Participation in NetSci High has made me realize that networks are in almost every fabric of life. With this knowledge, I believe that I understand the importance of having a functioning and successful network of people around you, not just doing academic work, but also in life.*

ii. Skill acquisition:

- *This project has provided me with the three chief skills of a 21st century citizen. These are analytical skills, interpersonal skills, and technological skills.*

- *[NetSci High] has changed my perspective on topics, in both academic and "real world" settings. Helped me gain new knowledge about networks, and non-network items (such as coding, team/social skills, and computer proficiency). NetSci High has changed my problem-solving thinking. It's awesome!!*
- *Due to my participation in NetSci High, my overall understanding and skills revolving around computer coding and analyzing networks has changed for the better. My coding skills and analyzing of networks have been greatly enhanced. My participation has impacted my plans for the future by having me think about a future of computer science-related work.*

iii. Self-efficacy

- *NetSci High has taught me the value of studying networks and systems as an interdisciplinary science and tool for understanding all sorts of problems. Before this program I had never considered this value of studying networks, and now I am confident in my ability to understand and communicate information surrounding the study of networks both at a high level and using a more technical approach. I can no longer "unsee" the world around me in terms of networks and its interconnectivity. Thank you NetSci* [High] *organizers!*
- *I've learned how to use resources more effectively. For instance, before NetSci High, I would never have written an email to some random professor/scientist. However, after NetSci High, I am not that intensely shy anymore.*
- *I have already accepted a place in research of biofilms (microbiology) at Binghamton University and hope that I will have the opportunity to utilize the skills I learned through my experience in NetSci* [High]. *This has been one of the more influential experiences in my high school career.*

iv. Changes in study and careers

- *After NetSci High I began to become interested in attending postsecondary institutes of technology and pursuing computer science as a major in university/college.*
- *I found this project to be absolutely incredible. Overall, this project gave me so much more than I could ever have expected or imagined, and I am incredibly appreciative of this opportunity. I wish it was possible to integrate this program on a larger scale, throughout all of America, as it has changed my life, and motivated/inspired me to go into network science research, and I can only imagine what it could for other students. Thank you so much for this opportunity.*
- *Participating in NetSci* [High] *really affected my plans for the future. After NetSci* [High] *I was really interested in the whole concept of network science. In my Cisco class, my teacher really helps me learn more about this. NetSci High is an amazing program, which I believe was very influential in my life*

because ever since Boston and the whole project, I started talking about this with my friends.

- *The NetSci High experience was one of the best experiences of my life. It allowed me to do research earlier than most people. I learned the process of research and solving complex problems as a group. Furthermore, I learned that networks are all around us. I was able to apply networks, particularly to medicine, which I have always had a passion for. I hope to be able to continue using networks in other research that I will pursue in college and the future. I hope to apply networks to whatever field I choose to go in.*

The teacher survey was constituted by three open-ended questions that asked about student network learning, student skills development, and a sustained student interest in careers. For each of the three questions, the teachers were asked to reflect on their own learning, their own network skills development, and the potential for sustained effects on their own practice. Six teachers from four schools responded to the survey. The following lightly edited sample of responses breaks down the themes by construct with the effects on teachers and effects on the teacher herself mixed together (as they were in the actual responses).

<u>i. Helping students learn about networks</u>

Teachers tended to cite the value of the more theoretical learning, with a special emphasis on the innovative qualities of the NetSci High project. What the students, and teachers, learned in this project was decidedly not something they were likely to have otherwise gathered.

- *My students have come a long way in their understanding of networks. I believe that the time at BU was extraordinary in teaching the students about networks. They repeatedly refer to things they heard during their time at BU.*
- *NetSci High is the most productive and far-reaching project that I have mentored and interacted with students. Our students had absolutely no idea what network science entailed when we embarked on this project three years ago. We were learning nodes, edges, betweenness, clustering coefficients, centrality, and eigenvector together. We learned from each other.*
- *This project has not only been invaluable to the learning of our students, but also for myself. My knowledge of network science has grown exponentially over these three years.*
- *The students have learned a great deal about networks and basic computer programming. I have learned a lot about network tools and approaches.*

<u>ii. Helping with skills development</u>

The teachers were highly appreciative of the new technical skills, with these skills clearly seen as having a distinct educational value.

- *[The students] have become more analytical, which was evident during their poster presentation at CompleNet 2015. This project has introduced me to an up-and-coming field which I was previously unfamiliar with.*
- *All of the students have developed good skills in the use of software, i.e., Gephi, R, and others. This has resulted in a greater interest in coding, and in dealing with networks of increasing complexity. [My] learning Gephi has added a new, different perspective.*
- *My students have developed tremendous Python programming skills and the ability to generate network analyses within the toolboxes for Python. This project has helped me develop a comfort level in regards to supervising research outside of my expertise.*

iii. Developing an interest in careers involving networks

Note in the following that the teachers saw NetSci High as having enormous educational value, with the network perspective likely to continue to influence the participating educators' approach to certain content. The previous finding that many students intended to continue to study networks, or to incorporate networks in their future studies, was confirmed by the responding teachers.

- *I see a much better and more intense interest in the students that participated in NetSci when compared with those that didn't. I often refer to and use examples from the week at BU when teaching.*
- *Overall, the experience for high schoolers is fantastic. The week of boot camp* [summer intensive workshop] *focusing on topic without outside distraction. Exposure to world-class researchers and presentations. College-level experience, lecture environment. Meeting [other] students and making friends with students from other cities. Awesome experience, one they will remember forever. Absolutely invaluable.*
- *We have former students who were in NetSci High who plan to continue studying computer coding and computer science. Students who were in NetSci High last year have continued to carry on their research project with further studies and network science analysis this year on their own. Our students have grown to become independent thinkers who are able research, analyze, and visualize results. Networks are all around us and students in high school in the 21st century are so technologically connected that I feel it is imperative to incorporate network science in my teaching strategies, whether it involves biology, chemistry, or forensic science.*

Both qualitative and quantitative data indicate that Network Science for the Next Generation was consistently effective over the 3 years of the project in reaching its most basic goals of improving students' understanding of networks, their self-efficacy with regard to the study of networks, the attribution of value regarding networks, and their intentions to continue to study networks. The following table summarizes these conclusions by construct:

Table 10: Summary Findings by Construct. Indications are that Network Science for the Next Generation was effective over all three years of the program.

Construct	**Findings**
Understanding of networks	Students grew in their understanding of networks, and they reported assigning a strongly positive value to this new understanding
Skills acquisition	Students grew in their technical computing skills and applied these skills to their collaborative projects. The technical skills and social skills were developed largely in tandem under the tutelage of the faculty mentors.
Self-efficacy	Students expressed confidence in their teams, and well as in their own capacities, to be successful at the network research project.
Intentions to continue	Many students expressed clear intentions to continue to use their newly-developed skills and understanding of networks in their future studies. The boot camp was likely helpful in “demystifying” the college experience for many, laying the foundation for the future translation of NetSci skills into college studies.

4. Extension of NetSci High Model

The NetSci High model was continued from 2015 through 2020 between NetSci High partners Binghamton University and Vestal High School with NSF support.[7] Student teams presented their findings in the poster session at NetSci 2017 and 2019, CompleNet9 in 2018 and The Northeast Regional Conference on Complex Systems in 2020. A sampling of projects includes:

- *How behavioral attributes affect the cohesiveness of society: An agent-based social network simulation* [24];
- *A network-based analysis of educational outcomes of universities in the United States* [25];
- *How will the transfer of using alternatives to fossil fuels affect trade networks and economic interconnectedness?* [26];

[7] Computational Understanding of Living Systems/Life and Society (COULS) high school research program.

- *Music intervals connecting music of different cultures* [27];
- *What factors in a society affect creativity the most?* [28];
- *Interaction between temperature fluctuation and migratory behaviors of marine species* [29];
- *Effects of availability of human resources and financial resources on the performance of schools* [30];
- *Correlation between socioeconomic risk factors and HTT gene mutations leading to neurodegenerative autosomal-dominant diseases* [31]; and
- *The viability of wealth-based post-secondary educational affirmative action* [32].

Student reflections over the 4 years of COULS reveal a dramatic increase in the sophistication of language used to describe experience, a deepened understanding of the nature of science inquiry and the research process, self-efficacy, and the benefits of having diverse perspectives both on the nature of the science problems themselves, and the tools and processes needed to design end execute robust science experimentation. They are organized in accordance with the Byars-Winston 3 "C's" of retention factors.

Contextual: Many students described how their experience participating in COULS gave them new or improved skills such as: *"By presenting at conferences, receiving professional guidance and criticism" "think about the future"* and *"think more deeply and differently about our topic in ways that I wouldn't have been able to do before."* Many students remarked on novel experiences and new realizations: Becoming aware of the "*endless paths*" *open to research*" and "*There is a large difference between researching a person for history and conducting research with data in order to draw conclusions on the world*." And "*In the future I plan to do more research; I could not have asked for a better experience. The entire event was a life changing experience, and has convinced me to pursue doing more and different research in the future*."

Participants also gained new understanding about science: "*The hardest part of research is creating the research question. I was very surprised that the research question takes the most time to perfect*." And "*Science has a method, but it can start anywhere and jump into unexpected tangents and connections. It is messy and often surprising, but that's what makes science interesting! Any bit of data might spark the inspiration for new discovery at any moment, continuing humanity's endless string of greater discovery. I met professors and PhD students and felt pride in our work*."

Cognitive: Many participants noted that the experience would likely affect their academic career: *"It has shaped my aspirations of pursuing research in the future."*

"It has been an invaluable experience that has ultimately influenced my plans for college. Exposure to the computational side of research has inspired me to pursue a computational biology major. In addition, this year's experience exploring the socioeconomic influences of biological phenomena has interested me in also pursuing applied economics or public health in college." "I have gained skills involving collaboration and data processing that can be applied to other academic areas. I now know that research, especially into network sciences, is a thing that I am truly interested in and would love to incorporate into my future career." "The conferences have allowed me to take my first steps towards performing independent research and learning about the findings of others in various fields across the world. I had the opportunity to thoroughly research a topic that was very relevant for me, since I had to make a decision about where to go to college, and I had a chance to use what I learned by doing this project and apply it to my life."

Cultural: Working closely together on a mentored team provided new insights for participants: *"I learned how it is best to be open minded when brainstorming ideas, and that some ideas that you had initially not thought of may be interesting to explore." "I found this experience to be unique from other lab internships or research groups that I have been involved in because of the extensive mentorship and guidance that accompanied the research process." "By looking at statistics, family income, income deviation, and accentuating the flaws in current affirmative action, I helped my group incorporate a more inclusive policy that would serve and benefit all groups in the most efficient way possible. Furthermore, the highlight of our research was applying it to real-world scenarios and posing the notion that society will be "fairer" if our policy is used."*

5. Conclusions, Limitations and Recommendations

The dramatic impact on teaching and learning in NetSci High throughout a decade of experience corroborated our hypothesis that students would find network science to be motivating, highly engaging, and that with the right support structure would lead to success with students and teachers. We believe the model developed and tested over the life of the NetSci High program has implications for broadening participation and cultivating interest in STEM, increasing inclusion and equity in higher education and increasing diversity in science careers.

Students reported high levels of engagement in projects that used real-world, active learning in highly collaborative teams. Clearly the students worked hard on their projects, and while they expressed confidence regarding their work, they often alluded to anxieties they experienced in either completing the work or in the presentation of the work. Overcoming the social barriers to collaboration, the technical and logistical challenges, and the more psychological challenges all proved to be of great worth to the participating students. The role of the faculty and graduate student mentors was undoubtedly of great value here, as they provided prompt and clear feedback as the projects developed. This combination of meaningful challenge and attentive and thoughtful guidance is, we hold, of the greatest educational value.

NetSci High was clearly very innovative in both structure and content, with both student and teacher participants learning a great deal that they saw as having an enduring value. The preponderance of qualitative and the survey data as well as impassioned reflections from participants clearly support these claims. We conclude then that the great value, both cognitive and affective, that can be uniquely associated with participation in the NetSci High projects would not otherwise have occurred, and that this participation has exercised a consistently positive and readily distinguishable set of effects on the participants.

Limitations to our claims and inferences must also be considered. Because of the iterative design and execution of the program, the way it evolved, and how the configuration differed both among and within projects, the use of validated instruments was not possible under the constraints of the program. In addition, the number of participants in each cohort was too small to develop an in-house validated instrument. The distinctness of the projects meant that even the treatment of participation varied more or less from team to team. Combining these limitations with the lack of useful comparison groups, the shifting research strategies of the program, and the unknown duration of any enduring effects are confounding factors for making more generalizable claims on program effectiveness. Our attempts to follow students into their careers was also limited.

Recommendations for future study include a more refined use of the theoretical framing along with more recent findings in SCCT over the past decade since NetSci High was initiated, the use of more formalized methods that can be deployed over a period of time, a narrowing of constructs that are more amenable to quantification and settling on assessment instruments that can be examined for their psychometric robustness. Of course, a larger pool of participants would aid in the use, or development of validated instruments. On the other hand, gathering much more formative data in a more structured way would allow grounded theory to be better used to understand cognitive changes over time. Also, developing better, more strategic models of research, including the collection of data on moderating contextual variables that can affect local NetSci High teams will help understand environmental effects, and finding ways to gather longitudinal data on the enduring effects of participating in the NetSci High program would be of value.

Finally, as a part of the process of developing and executing the NetSci High program we made freely available all curriculum materials created through the program along with a variety of educational resources, including a full set of network literacy essential concepts in 20 languages on a website[8]. We also continue to sponsor an annual symposium to build a community of practice around network science in education.

Acknowledgements

NetSci High is supported through NSF Awards No. 1027752, 1139478, 1139482 and 1509079. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

[1] Barabási, A. L. (2016). Network science. Cambridge University Press.
[2] Börner, K., Sanyal, S., & Vespignani, A. (2007). Network science. In Blaise Cronin (Ed) Annual Review of Information Science & Technology, 41(1). Medford, NJ: Information Today, Inc. American Society for Information Science and Technology. pp. 537-607.
[3] Havlin, S., Kenett, D. Y., Ben-Jacob, E., Bunde, A., Cohen, R., Hermann, H., ... & Portugali, J. (2012). Challenges in network science: Applications to infrastructures, climate, social systems and economics. The European Physical Journal Special Topics, 214(1), 273-293.
[4] Lazer, D., Pentland, A., Adamic, L., Aral, S., Barabàsi, A-L., Brewer, D., Christakis, N., Contractor, N., Fowler, J., Gutmann, M., Jebara, T., King, G., Macy, M., Roy, D. & Van Alstyne, M. (2009) Computational social science. Science 323, 721.
[5] Molontay, R., & Nagy, M. (2019, August). Two decades of network science: as seen through the co-authorship network of network scientists. In Proceedings of the 2019 IEEE/ACM International Conference on Advances in Social Networks Analysis and Mining (pp. 578-583).
[6] Newman, M. E., Barabási, A. L. E., & Watts, D. J. (2006). The structure and dynamics of networks. Princeton university press.
[7] Anderson, M., & Jiang, J. (2018). Teens' social media habits and experiences. Pew Research Center, 28.
[8] Pai, A., Cole, M., Kovacs, J., Lee, M., Stovall, K., & McGinnis, G. (2017). As long as you are here, can I interest in you some science? Increasing student engagement by co-opting a social networking site, Facebook for science discussions. Journal of Educational Technology Systems, 46(2), 153-177.

[8] https://sites.google.com/a/binghamton.edu/netscied/

[9] Vidales-Bolaños, M. J., & Sádaba-Chalezquer, C. (2017). Connected teens: Measuring the impact of mobile phones on social relationships through social capital. Comunicar. Media Education Research Journal, 25(2).
[10] Lent, R. W., Brown, S. D., & Hackett, G. (1994). Toward a unifying social cognitive theory of career and academic interest, choice, and performance [Monograph]. Journal of Vocational Behavior, 45, 79-122
[11] Chubin, D., DePass, A., & Blockus, L. (2009). Understanding Interventions that Broaden Participation in Research Careers, Vol. III: Embracing a Breadth of Purpose! Summary of Third Annual Conference on Understanding Interventions that Broaden Participation in Research Careers, Bethesda, Maryland: May 7–9. Washington DC: American Association for the Advancement of Science. 31.
[12] Byars-Winston, A., Estrada, Y., Howard, C., Davis, D., & Zalapa, J. (2010). Influence of social cognitive and ethnic variables on academic goals of underrepresented students in science and engineering: A multiple-groups analysis. Journal of Counseling Psychology, 57(2), 205.
[13] DePass, A. L., & Chubin, D. E. (2008). Understanding interventions that encourage minorities to pursue research careers: Building a community of research and practice. Maryland: American Society for Cell Biology.
[14] Collins, A., Brown, J. S., & Newman, S. E. (1987). Cognitive apprenticeship: Teaching the craft of reading, writing and mathematics (Technical Report No. 403). BBN Laboratories, Cambridge, MA. Centre for the Study of Reading, University of Illinois. January, 1987.
[15] Orey, M. A., & Nelson, W. A. (1994). Situated Learning and the Limits of Applying the Results of These Data to the Theories of Cognitive Apprenticeships. Information Analysis, ERIC.
[16] Harel, I. E., & Papert, S. E. (1991). Constructionism. Ablex Publishing.
[17] Blansky, D., Kavanaugh, C., Boothroyd, C., Benson, B., Gallagher, J., Endress, J., & Sayama, H. (2013). Spread of academic success in a high school social network. PloS one, 8(2), e55944.
[18] Cohen, Jacob (1988). Statistical Power Analysis for the Behavioral Sciences. Routledge Press.
[19] Kruskal, W.H. & Wallis, W.A. (1952) Use of Ranks in One-Criterion Variance Analysis, Journal of the American Statistical Association, 47:260, 583-621, DOI: 10.1080/01621459.1952.10483441.
[20] Kolmogorov, A. (1933) Sulla determinazione empirica di una lgge di distribuzione. Inst. Ital. Attuari, Giorn., 4:83–91.
[21] Smirnov, N. (1948). Table for estimating the goodness of fit of empirical distributions. The annals of mathematical statistics, 19(2):279–281.
[22] Wilcoxon, F. (1945) Individual comparisons by ranking methods. Biometrics Bulletin, 1(6), 80–83. DOI: 10.2307/3001968

[23] Cronbach, L.J. (1951). Coefficient alpha and the internal structure of tests. Psychometrika, 16 (3), 297–334. https://doi.org/10.1007/BF02310555

[24] Sulicz, E. and Shaikh, J. Reynolds, C. and Sayama, H. (2018). Does it really matter where you go to college? A network-based analysis of educational outcomes of universities in the United States. Poster presented at the International Conference on Complex Networks , Boston, MA.

[25] Sulicz, E., Zhu, J., George, E., Nadeem, K., Van Donsel, A., Slogar, S-L., Reynolds, C. and Sayama, H. (2017). How Behavioral Attributes Affect the Cohesiveness of Society: An Agent-Based Social Network Simulation. Poster presented at the International School and Conference on Network Science, Indianapolis, IN.

[26] Vincens, C. Shah, D. Reynolds, C. and Sayama, H. (2018). How will the transfer of using alternatives to fossil fuels affect trade networks and economic interconnectedness? Poster presented at the International Conference on Complex Networks , Boston, MA.

[27] Barnes, H., Zhu, J., Reynolds, C. and Sayama, H. (2018). Music intervals connecting music of different cultures. Poster presented at the International Conference on Complex Networks , Boston, MA.

[28] Ashok, A., Shah, A., Reynolds, C. and Sayama, H. (2019). Interaction between temperature fluctuation and migratory behaviors of marine species. Poster presented at the International School and Conference on Network Science, Burlington, VT.

[29] Deskur, C., Shah, D., Vincens, C., Reynolds, C. and Sayama, H. (2019). What factors in a society affect creativity the most? Poster presented at the International School and Conference on Network Science, Burlington, VT.

[30] Kaneria, S., Cui, J., Guo, J., Reynolds, C. and Sayama, H. (2019). Effects of availability of human resources and financial resources on the performance of schools Poster presented at the International School and Conference on Network Science, Burlington, VT.

[31] Ashok, A., Reyen, C., Shah, A., Reynolds, C. and Sayama, H. (2020) Correlation between socioeconomic risk factors and HTT gene mutations leading to neurodegenerative autosomal-dominant diseases. Contributed talk presented at NERCCS 2020: Third Northeast Regional Conference on Complex Systems, April 1-3, 2020, Buffalo, NY (conference held online).

[32] Cui, J., Guo, J., Mehta, D., Ashok, A., Reynolds, C. and Sayama, H. (2020) The viability of wealth-based post-secondary educational affirmative action. Contributed talk presented at NERCCS 2020: Third Northeast Regional Conference on Complex Systems, April 1-3, 2020, Buffalo, NY (conference held online).