Select Stories on the Influence of QuarkNet on Teachers/Fellows and Former High School Students: Supplement II to the Final Evaluation Report in Support of NSF Grant #2039272

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Supporting Data-driven Decisions℠

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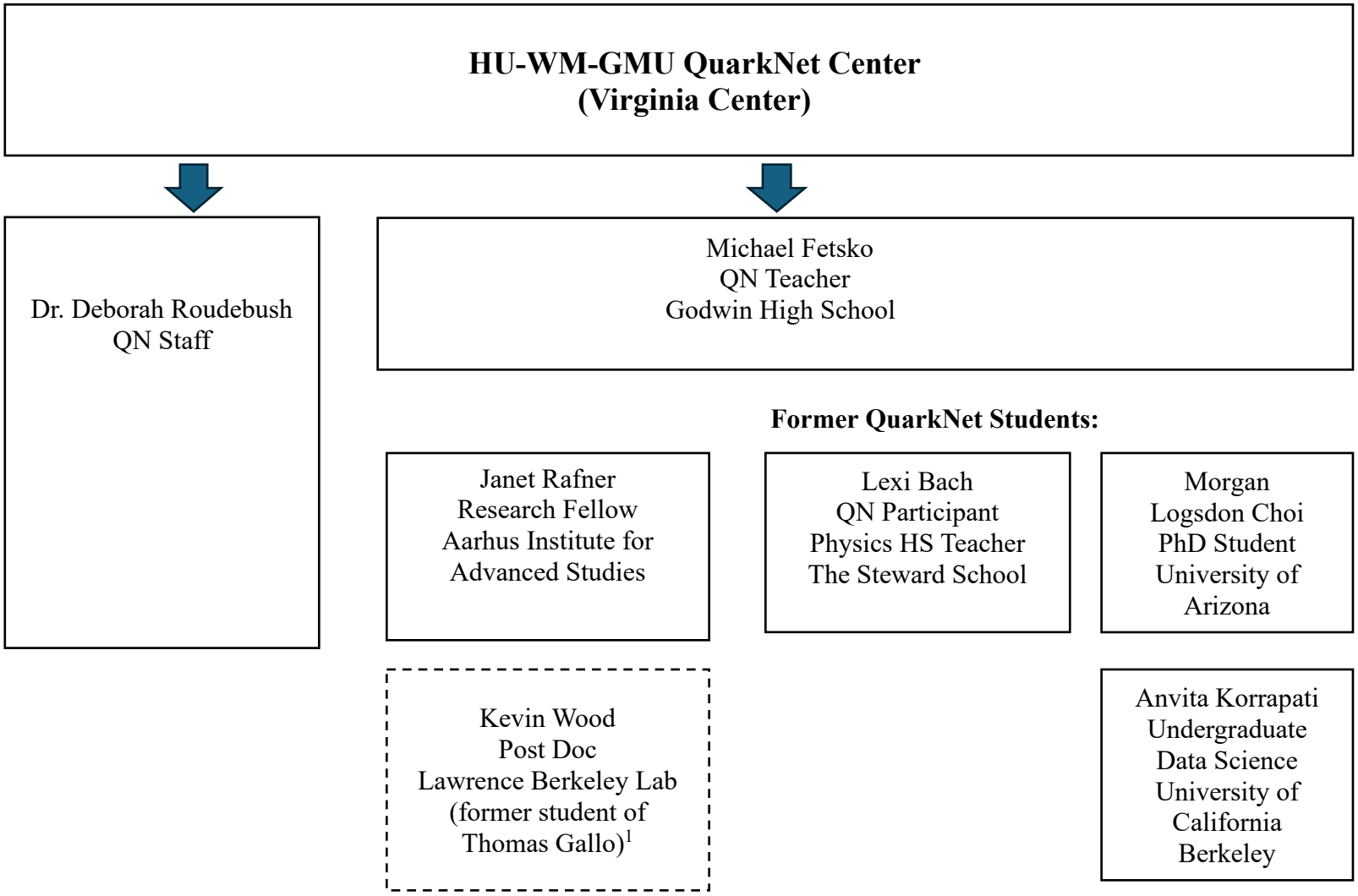
The following document is the second in a series of supplemental reports to the 2024 QuarkNet Evaluation Report and the Final Evaluation Report (2025) for the National Science Foundation's grant period of 2023-2025. Supplement II focuses on one QuarkNet Center (HU-WM-GMU also known as the Virginia Center). The report highlights the role that a QuarkNet staff member has had in its development, highlights a QuarkNet high school teacher from this center, and provides several examples of success stories from former high school students who participated in QuarkNet as students.

In accordance with the Guiding Principles for Evaluators Guiding Principles (eval.org) we have sought and received written approval from each individual included in a scenario who has reviewed and approved their story before its inclusion.

As implied by its name, this document is best viewed as a supplement to the final evaluation reports. These evaluation reports (e.g., 2024) present information on the implementation of the program and analyses on the important role that centers play in its implementation. We also look at the engagement level in the program through workshops, masterclasses, and other program events implemented by these centers. These reports provide information about QuarkNet participants and focuses on how QuarkNet influences teacher outcomes and long-term outcomes through this engagement. Center-level portfolios summarize responses to open-ended survey questions by participants over time focused on how teachers plan and have incorporated QuarkNet content and materials in their classrooms; and include proposed implementation plans, teacher work, and student work, when available. Program and evaluation recommendations are proffered as well.

QuarkNet Success Stories: Center Connections, Teacher Connections and Former Students



[1]Thomas Gallo (currently at Freeman High School in Henrico VA) and Michael Fetsko together conducted QuarkNet Masterclasses and laboratory tours when they both taught at Godwin High School at the time Kevin was in high school.

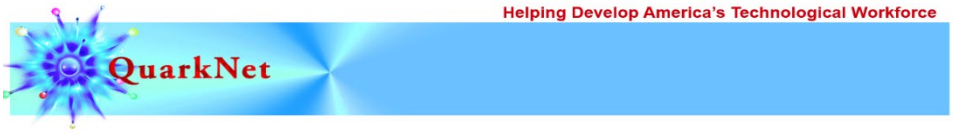
HU-WM-GMU
QuarkNet Center
(Virginia Center)

Deborah Roudebush QuarkNet Education Specialist (presented with permission)

Before retiring, Deborah Roudebush taught physics in Fairfax County Public Schools in Virginia for 30 years. She has a master's degree in physics (M.S.) from Michigan State University, and an Ed.D. from Ball State University in adult education, curriculum development and staff development, as well as evaluation. She received the Excellence in Pre-College Physics Teaching Award from AAPT in 2009.

During her QuarkNet involvement, Deborah has worn many hats. She joined QuarkNet in 2000 as a lead teacher for the Hampton University Center which over several years and through her tutelage evolved to the present-day HU-WM-GMU QuarkNet Center (Virginia Center). In 2007, she became a Teacher and Learning Fellow (at the start of this program) and helped support the original Boot Camp which is now Data Camp. During this time, she had the opportunity to engage in extended research with the late Ken McFarland. In 2014, she was placed in charge of the Data Activities Portfolio (DAP) activities to help ensure that these materials met the criteria of good design and high quality. She anchored this effort by incorporating a claims/ evidence/ reasoning approach in line with McNeill & Krajcik (2008) as well as the backward design approach proffered by Wiggins and McTighe (2005), that is identifying desired results, determining what counts as evidence and then determining if students did (or did not) achieve those results. And she has been instrumental in aligning these materials with the Next Generation Science Standards (2013) and the Enduring Understandings outlined by QuarkNet Principal Investigators and Staff. She also focused on integrating activities across an array of student skill sets, building upon skills to help encourage the use of the materials by teachers across a larger swath of students and curriculum topics. In 2018, she joined QuarkNet as a staff member in this capacity. In this role, the number and quality of DAP activities has increased substantially, with a growing number now in Spanish as well.

Deborah has presented as numerous meetings at the AAPT meetings an example is shown below (Spring Meeting of APS, 2022).



Data Activities Portfolio:

A Research Based Approach for Infusing 21st Century Physics into the High School Classroom

Deborah Roudebush

QuarkNet Education Specialist

Michael Fetsko
QuarkNet Teacher and Fellow
(Used with his permission 6/28/2024)

Michael Fetsko joined QuarkNet as a participating teacher in 2000, then in 2004 he joined the QuarkNet Boston Area Center. In 2007, he joined the HU-WM-GMU QuarkNet Center (Virginia Center) as a lead teacher and a LHC fellow. Fetsko is an experienced Physics teacher at Mills Godwin High School in Henrico, VA a suburban school with about 13% of the student body in their free or reduced lunch program. Over the years, he has taught AP Physics 1 and 2 as well as Honors Physics. Since 2008, he has been the Science Department Chair at Godwin.

Testimonial (January 2018)
MikeFetsko_VA.pdf (quarknet.org)

Michael wrote:

I joined QuarkNet in the summer of 2000 and have been an active participant ever since, including becoming an LHC fellow and making numerous presentations on my incorporation of particle physics in my classroom. The people that I have met and have had the pleasure to work with has made my joining QuarkNet the best professional decision I have made in my career. From the beginning, I realized that there is great value to teaching particle physics simply to provide a students a sense that there is still so much to learn in physics! Over the years, I have included a unit (between one to three weeks) in my classes specifically designed to teach my students about the wonder of the particle world. In the beginning, a lot of what I did was worksheet driven and lectures, but over the years the resources that QuarkNet has developed and provides all of us have made my instruction a lot more student inquiry focused and a lot less teacher centered. Whether my students are looking at historical bubble chamber images to learn about charge, momentum and energy or analyzing real events from the CMS and ATLAS detectors…they are engaging in real physics research and getting an actual idea of what life as a physicist is really like. I would say that my involvement with QuarkNet has been inspirational, for me and for my students. My students have worked with the Cosmic Ray Muon Detector analyzing data and creating posters. A few students have actually used the CRMD for science fair projects and have done very well. The CMS elab has been a staple in my course since it was created. My students find it challenging, but many of them do enjoy creating their own research projects and publishing them for others to read. Finally, the most important project that my students experience is the Masterclasss Day. To call it life-changing is not an understatement… EVERY year I have a student (and sometimes many more) who attend the event and come away with the feeling of "I'm going to do this…I'm going to be a physicist". I have been taking students to Masterclass since 2008 and every year it is a highlight for all involved. Just from that first year, one of my students went on to major in physics and has become a teacher with me at Godwin HS. She has also become a QuarkNet member! Another young lady, went on to major in physics and continued her work in Europe and recently received her PhD and is currently living in Berlin working on the IceCube project. This was just the first year…the physics majors have continued with each year.

It's actually quite simple…QuarkNet provides teachers the knowledge and resources to inspire the next generation of physicists.

QuarkNet Engagement and Highlighted Responses from Survey

As a long-term QuarkNet teacher and fellow, Michael has participated in and/or helped lead the following QuarkNet events as examples of his engagement:

- Data Camp
- CERN Summer Program
- CMS Data Workshop
- CMS e-Lab Workshop(s)
- Cosmic Ray e-Lab(s)
- Neutrino Data Workshop(s)
- ATLAS Masterclass(es)
- CMS Masterclass(es)
- World Wide Data Day

He has also participated in Lead Teacher and Fellows workshops to help hone his leadership skills as well as contribute directly to improving and implementing QuarkNet programs.

How Michael has reported use of QuarkNet DAP activities in his classroom.

In 2019, he wrote: *They are a great resource and provide a way to introduce modern topics in physics to your students .. this will give the students a sense that physics is not dead and that there is a lot left to be learned*. He specifically mentioned the Z Boson activity.

In 2021, he wrote: *I teach a "unit" of four class days to my AP Physics 1 students, covering Standard Model, bubble chambers, and masterclass activities.* He mentioned these examples: bubble chamber, Z Boson, J/psi.

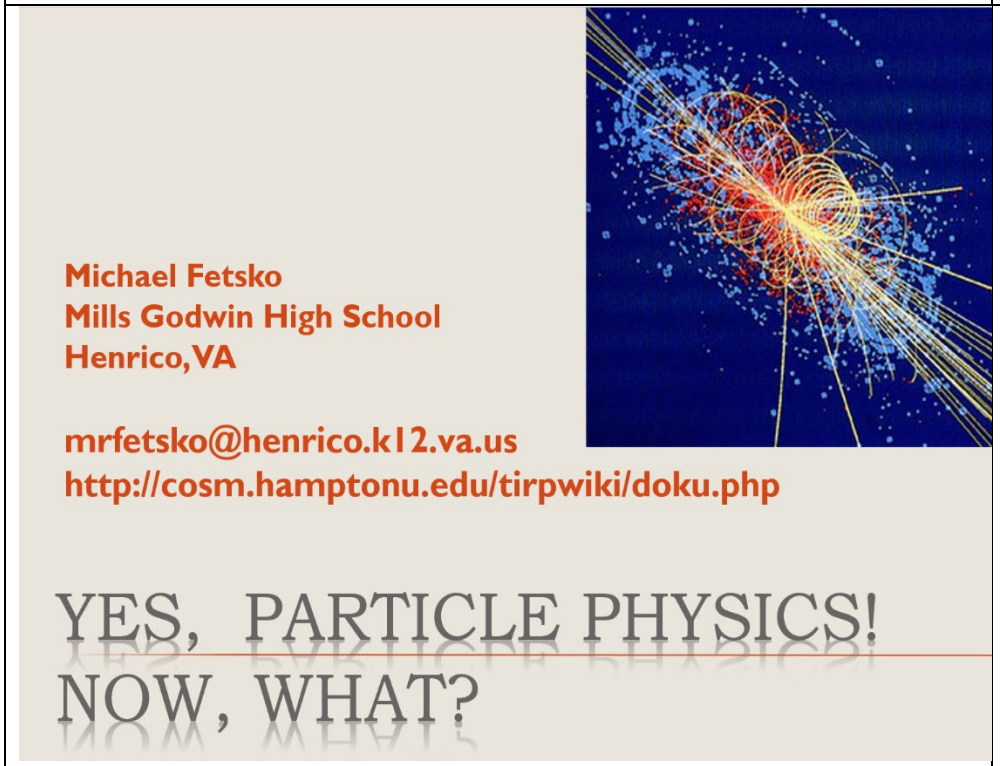
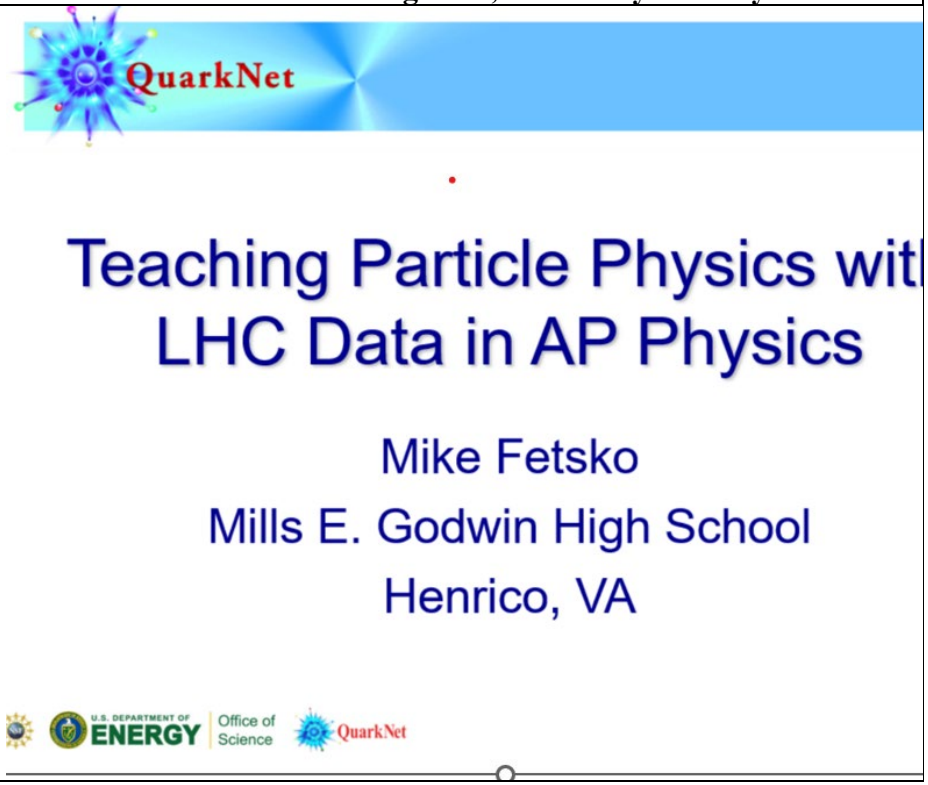
In 2022, he wrote: *Use some of the activities in a mini-unit on particle physics in my AP Physics 1 class. Attend masterclass with students.* He mentioned these examples: Z boson, making tracks, CMS e-lab.

In 2023, he wrote: *Z -boson...great way to teacher vector addition and particle physics at the same time. Great activities that hit a variety of physics topics that can be integrated into physics curriculum.*

Michael wrote in response to an open-ended question about QuarkNet (2023), *The single most valuable professional experience of my career. The access to physicists has been awesome...love talking with them, asking questions, etc. A highlight of my teaching career!*

Michael is the author of several Particle Physics instructional materials. He authored *The Standard Model of Particle Physics, 21st Century Physics Flexbook: A Compilation of Contemporary and Emerging Technologies,* http://flexbooks.ck12.org/flexr/, February 2009 as well as *Finding the Mass of the Z Boson Exercise*, http://ippog.org/resources/2012/mass-calc-z, Fall 2012, the latter of which is referred to in the above quotes about QuarkNet content and materials used in his classroom and is a QuarkNet Data Activities Portfolio activity Data Activities Portfolio | QuarkNet. He credits QuarkNet for helping him develop his physics knowledge and skill sets as well as offering him support through collegial relationships and seeking and using resources he has used to engage his students in his classroom. And he credits his students' enthusiasm for stoking his passion for Physics. Many of his former students have returned to his classrooms for in-person or video conferences for his current Physics classes. And many of his former students are featured in their own QuarkNet related success stories. A common theme in many of his presentations is addressing how to teach particle physics in the classroom. Of importance, he noted a common experience for all of his former students who are now pursuing a career in physics or in physics education is that each participated in a QuarkNet masterclass.

Two Presentations by Michael Fetsko

APPT TalkW10	AAPT Summer Meeting 2015, University of Maryland
	

Janet Rafner, PhD Research Fellow,
Aarhus Institute for Advanced Studies, Aarhus University
Former Student of Michael Fetsko Mills Godwin High School in Henrico, VA
Virginia QuarkNet Center
(Used with permission)

Testimonial (January 2018) MikeFetsko_VA_studentJanetRaffner.pdf (quarknet.org)	Academic Achievements
High school physics is a challenging experience even if one is good at math and loves science. There are many tangible experiments (such as the famous mousetrap car competition) that build understanding of fundamental principles in physics. However, the moment class dives down into subatomic particles, we move into an abstract world where most students' eyes glaze over. That is where the NSF QuarkNet Masterclass came in – and changed the course of my academic life. The Masterclass gave me a taste of real scientific research in a feet-on-the-ground experience that had a huge impact early in my academic pursuits. It was the first time I had seen the equations and case studies applied in context. While I ultimately have chosen not to focus on research in particle physics, it was crucial to my grasping the complex, emergent properties of matter, and provided the impetus to embrace research and science engagement as a career. The QuarkNet funded activities and the inspiration fostered by my teacher, Mr. Fetsko had such an impact on me that I still frequently speak about it as one of the defining points of my academic life. These types of activities that provide exposure to research are simply essential if we hope to motivate a new generation of young people to pursue the sciences, and to grasp the key role elementary particles play in defining how the world works. *P.S. One of the outgrowths of my QuarkNet Masterclass experience was to later create/author the "Physics Outreach" Wikipedia page, which included the role of QuarkNet.*	Janet Rafner: • BSc in Physics with a minor in Studio Art, from the University of Virginia, Charlottesville, Virginia. (2015) • A Fullbright Fellow (United States) with Dr. Rikke Schmidt Kjærgaard (visualization of complex phenomena) at the iNano Data Visualization Center, Aarhus University (2015-216). • MSc in Physics with Joachim Mathiesen (theoretical fluid dynamics), Niels Bohr Institute, Copenhagen University: "Turbulence Games"; Co-supervised by Jacob Sherson (Aarhus University), Zoran Grujic (University of Virginia) and Robert Feidenhans'l (2018) • She was the Junior Center Director, Center for Hybrid Intelligence, Aarhus University (starting in July 2018) • PhD, Information Communication Technology (with Kristian Tylén, Aarhus University (2022). Her dissertation is entitled: "*Exploring Human-AI Interaction in Hybrid Intelligence and Creativity through Crowdsourcing and Games"* After completing her doctorate, Dr. Rafner received a Postdoc, in the Department of Linguistics, Cognitive Science and Semiotics and Center for Hybrid Intelligence, Department of Management, Aarhus University. (2022-2023) She is currently, a Research Fellow, Aarhus Institute for Advanced Studies, Aarhus University. Her academic focus is on: Human-AI co-creativity, hybrid intelligence, human-centered AI, citizen science, participatory democracy. She has received numerous awards and the recipient of many grant and seed money funding sources.

Janet Rafner: Select Publications

Beck, Susanne, Carsten Bergenholtz, Marcel Bogers, Tiare-Maria Brasseur, Marie Louise Conradsen, Diletta Di Marco, Andreas P. Distel et al. "The Open Innovation in Science research field: a collaborative conceptualisation approach." *Industry and Innovation* 29, no. 2 (2022): 136-185. 13662716.2020.1792274 (tandfonline.com)

ABSTRACT

Openness and collaboration in scientific research are attracting increasing attention from scholars and practitioners alike. However, a common understanding of these phenomena is hindered by disciplinary boundaries and disconnected research streams. We link dispersed knowledge on Open Innovation, Open Science, and related concepts such as Responsible Research and Innovation by proposing a unifying Open Innovation in Science (OIS) Research Framework. This framework captures the antecedents, contingencies, and consequences of open and collaborative practices along the entire process of generating and disseminating scientific insights and translating them into innovation. Moreover, it elucidates individual-, team-, organisation-, field-, and society-level factors shaping OIS practices. To conceptualise the framework, we employed a collaborative approach involving 47 scholars from multiple disciplines, highlighting both tensions and commonalities between existing approaches. The OIS Research Framework thus serves as a basis for future research, informs policy discussions, and provides guidance to scientists and practitioners.

https://hcjournal.org/index.php/jhc/article/view/133/121

Human Computation (2022) 9:1:66-95

ISSN: 2330-8001, DOI: 10.15346/hc.v9i1.133

ABSTRACT

Artificial Intelligence (AI) can augment and sometimes even replace human cognition, but still has many fundamental roadblocks preventing it from achieving fully autonomous applications. Inspired by the growing set of AI-implementation failures in society at large, in this opinion piece we reexamine the field of Citizen Science (CitSci) through a computational lens, highlighting algorithmic opportunities as well as uniquely human capabilities. In particular, we situate the CitSci field among human and machine computation fields and introduce two novel dimensions allowing us to match CitSci projects ranging from digital games and annotation tasks to data collection in nature to the appropriate machine learning algorithms. Interestingly, in CitSci there is an abundance of tasks drawing upon human common sense, hierarchical thinking, and complex skills which have yet to be incorporated in current AI methods. This gap, combined with the unique participant-centered set of values, makes CitSci an invaluable test bed for the development of human-centered AI of the 21st century such as hybrid intelligence. The mapping thus offers concrete algorithm selection guides to CitSci researchers as well as inspiration for AI researchers to pursue grand AI challenges through support of CitSci projects.

Jensen, Jesper Hasseriis Mohr, Miroslav Gajdacz, Shaeema Zaman Ahmed, Jakub Herman Czarkowski, Carrie Weidner, **Janet Rafner,** Jens Jakob Sørensen, Klaus Mølmer, and Jacob Friis Sherson. "Crowdsourcing human common sense for quantum control." *Physical Review Research* 3, no. 1 (2021): 013057. PhysRevResearch.3.013057 (aps.org)

PHYSICAL REVIEW RESEARCH **3**, 013057 (2021)

Crowdsourcing human common sense for quantum control

Jesper Hasseriis Mohr Jensen, Miroslav Gajdacz, Shaeema Zaman Ahmed, Jakub Herman Czarkowski, Carrie Weidner, Janet Rafner, Jens Jakob Sørensen, Klaus Mølmer, and Jacob Friis Sherson*

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Citizen science methodologies have over the past decade been applied with great success to help solve highly complex numerical challenges. Here, we take early steps in the quantum physics arena by introducing a citizen science game, *Quantum Moves 2*, and compare the performance of different optimization methods across three different quantum optimal control problems of varying difficulty. Inside the game, players can apply a gradient-based algorithm (running locally on their device) to optimize their solutions and we find that these results perform roughly on par with the best of the tested standard optimization methods performed on a computer cluster. In addition, cluster-optimized player seeds was the only method to exhibit roughly optimal performance across all three challenges. Finally, player seeds show significant statistical advantages over random seeds in the limit of sparse sampling. This highlights the potential for crowdsourcing the solution of future quantum research problems.

DOI: 10.1103/PhysRevResearch.3.013057

In an email to me dated September 24, 2024, Janet wrote: *Fifteen years later I look back at my time in Mike Fetsko's class and reflect on how much it helped shape who I am personally and professionally. Mike pushed me not only to be a curious, engaged, diligent learner, but also to balance hard work with enjoying life and friendships; to take my work very seriously but take myself a little less seriously. It has been an honor and a pleasure to stay in touch with Mike over the years and speak to his class on multiple occasions about physics, study abroad, and life as an academic. Now, at 31, I have an eight month old daughter who is just beginning to engage with the world with bright and curious eyes. I can only hope that one day she will be lucky enough to have a teacher in her life who will be a positive influence on her as Mike Fetsko was for me.*

Kevin Wood, PhD
Former Student of Tom Gallo, Mills Godwin High School in Henrico, VA
HU-WM-GWU QuarkNet Center (Virginia Center)
(Used with permission)

Early Years	Academics
I spoke with Kevin on September 10, 2024, during a Zoom meeting When I asked Kevin when he developed an interest in science, he said that his interest gradually increased over the years when he was very young and that he had a bit of *ah ha* moment when he was older during his high school Physics class. He said that he was always drawn to mathematics and appreciated the logic and process to both math and science as an application of math. As a senior in high school, during his Physics class, Kevin described how they had gotten through the standard curriculum and toward the end of the year. He, he said his *ah ha* moment came when he and fellow students spent a couple of weeks talking about modern physics, such as seeing pictures of the LHC, exploring ATLAS and CMS detectors as well as the technology that was being developed to try to answer deep, philosophical questions. He said that they were taking science and math – and then applied and using it to ask (and answer) these interesting questions. His physics teacher was Tom Gallo who worked closely with Mike Fetsko.	Before applying to the University of South Carolina (USC), he went to visit the university and he said he immediately felt at home, the atmosphere of balance of academics, sports and a beautiful setting. When as part of his acceptance package, he was accepted into the Honors College in their Capstone program, he indicated that sealed the deal for him. Although he had an *ah ha* moment in high school, he was still deciding on a major between math, engineering or physics. He said that it took about a semester or so to figure out that he wanted to major in physics (with a double major in math) and to pursue a career in physics. He was really interested in getting involved in academic modern physics research. Through his undergraduate research, he took the opportunity to sample different subfields of physics, doing experimental work, doing theoretical work, and he did work in condensed matter, nuclear physics and high energy physics. Eventually, he was drawn to the projects that he had done in high energy physics, which became the focus of his Ph.D., and he is continuing along that field during his current post doc at the Lawrence Berkeley National Laboratory as a Chamberlain Fellow.
Undergraduate Degree Kevin's undergraduate education was at University of South Carolina, Columbia (2010-214). He has a BS Physics and Mathematics, Honors College (2010-2014) and a Capstone Scholar (2010-2012). His thesis was, *The Long-Baseline Neutrino Experiment and LArTPC Energy Resolution*.	**Staying on an Additional Year** After receiving his bachelor's degree (BS Physics and Mathematics), he spent at additional year at USC continuing the research that he did as undergraduate (2013-2015 Research Assistant, Professor Sanjib Mishra, University of Carolina).

Kevin Wood, Ph.D. He is currently a Chamberlain Fellow at Lawrence Berkeley National Laboratory (LBL).

Graduate Education	PhD and Post-doc
Kevin accepted an offer to enroll in the graduate program at Stony Brook University, Long Island New York. Prior to accepting the offer, he spoke with a professor who eventually became his Ph.D. supervisor; this lab was doing work related to what Kevin had done as an undergraduate (2016-2021, Research Assistant to Professor Chang Kee Jung, Stony Brook University). Kevin said that one reason that he picked Stony Brook was the large size of the graduate program, a lot of students and a variety of options and he sought out these challenges. Kevin indicated that during his first two years, he focused on course work, the background knowledge he desired to make sure that he had a solid foundation including exposure to theoretical physics. During the summer, he focused on research. After his first two years of course work, he sent 18 months at CERN in experimental particle physics – building a particle detector, learning how experiments work, the design, the construction and operation phases of these; practical applications of what he had learned. The large collaboration of people, often necessary in the conduct of experimental physics, was a plus for him. He was most interested in neutrino oscillation analysis, working on long baseline neutrino oscillation experiments and sought experiments that extracted these neutrino oscillation parameters; the focus of the last two years of his Ph.D. program. He was involved in two different projects during this time, one was the DUNE experiment which at the time was still in its R& D phase and still several years away from collecting its neutrino data. The other experiment is T2K which permitted him to conduct the analyses that he did for his thesis.	Kevin received a PhD in Physics, Stony Brook University (2015-2021) where he specialized in experimental high energy phsyics. His thesis title *Measurement of Neutrino Oscillation Parameters with T2K Data Corresponding to 3.6 x 10^{21} Protons on Target Using a Bayesian Framework.* Currently, Kevin is doing a post-doc at LBL a position he has held since 2021. As a Chamberlain Fellow, he is the Run Coordinator for the 2x2 Demonstrator of ND-Lar; Convenver of 2x2 Simulation and Callibration group; a L3 Manager of LArPix charge readout subsystem of DUNE ND-Lar near detector; and conducting T2K-NOvA joint oscillation analysis. (Source: Kevin Woods' CV.) **Outreach:** As part of Kevin's outreach efforts, he gave a presentation on *Neutrinos* during a virtual QuarkNet workshop conducted by LBL *Physics in and through the Cosmology* (with a group of ten LBL scientists participating). During this workshop, he also participated in a panel with a subgroup of these scientists during a Q&A session with the students. [According to the 2022 QuarkNet Report for the LBL center, a total of six physics teachers and 42 students participated in this workshop which was held during this 2-week period (June 21-July 21, 2022).] He has also given talks in high school classes on several occasions including Mike Fetsko's and Tom Gallo's high school classes. He said that he is drawn to high school presentations and to engaging high school students in part because of his *ah ha* moment that he had when he was in high school.

Kevin Wood Publications

JOURNAL ARTICLE

Measurements of neutrino oscillation parameters from the T2K experiment using 3.6×1021 protons on target

1 Jan 2023 ◆ European Physical Journal C ◆ 83(9):782

Abe K, Akhlaq N, Akutsu R ...397 more

Abstract The T2K experiment presents new measurements of neutrino oscillation parameters using $19.7(16.3) \times 10^{20}$ protons on target (POT) in (anti-)neutrino mode at the far detector (FD). Compared to the previous analysis, an additional 4.7×10^{20} POT neutrino data was collected at the FD. Significant improvements were made to the analysis methodology, with the near-detector analysis introducing new selections and using more than double the data. Additionally, this is the first T2K oscillation analysis to use NA61/SHINE data on a replica of the T2K target to tune the neutrino flux model, and the neutrino interaction model was improved to include new nuclear effects and calculations. Frequentist and Bayesian analyses are presented, including results on $\sin^2\theta_{13}$ and the impact of priors on the δ_{CP} measurement. Both analyses prefer the normal mass ordering and upper octant of $\sin^2\theta_{23}$ with a nearly maximally CP-violating phase. Assuming the normal ordering and using the constraint on $\sin^2\theta_{13}$ from reactors, $\sin^2\theta_{23} = 0.561^{+0.021}_{-0.032}$ using Feldman–Cousins corrected intervals, and $\Delta m^2_{32} = 2.494^{+0.041}_{-0.058} \times 10^{-3}$ eV^2 using constant $\Delta\chi^2$ intervals. The CP-violating phase is constrained to $\delta_{CP} = -1.97^{+0.97}_{-0.70}$ using Feldman–Cousins corrected intervals, and $\delta_{CP} = 0, \pi$ is excluded at more than 90% confidence level. A Jarlskog invariant of zero is excluded at more than 2σ credible level using a flat prior in δ_{CP}, and just below 2σ using a flat prior in $\sin\delta_{CP}$. When the external constraint on $\sin^2\theta_{13}$ is removed, $\sin^2\theta_{13} = 28.0^{+2.8}_{-6.5} \times 10^{-3}$, in agreement with measurements from reactor experiments. These results are consistent with previous T2K analyses.

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JOURNAL ARTICLE

Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC

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Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC

The DUNE Collaboration

E-mail: Stefania.Bordoni@cern.ch

Abstract: The ProtoDUNE-SP detector is a single-phase liquid argon time projection chamber (LArTPC) that was constructed and operated in the CERN North Area at the end of the H4 beamline. This detector is a prototype for the first far detector module of the Deep Underground Neutrino Experiment (DUNE), which will be constructed at the Sandford Underground Research Facility (SURF) in Lead, South Dakota, U.S.A. The ProtoDUNE-SP detector incorporates full-size components as designed for DUNE and has an active volume of $7 \times 6 \times 7.2\,\mathrm{m}^3$. The H4 beam delivers incident particles with well-measured momenta and high-purity particle identification. ProtoDUNE-SP's successful operation between 2018 and 2020 demonstrates the effectiveness of the single-phase far detector design. This paper describes the design, construction, assembly and operation of the detector components.

Keywords: Noble liquid detectors (scintillation, ionization, double-phase); Photon detectors for UV, visible and IR photons (solid-state) (PIN diodes, APDs, Si-PMTs, G-APDs, CCDs, EBCCDs, EMCCDs, CMOS imagers, etc); Scintillators, scintillation and light emission processes (solid, gas and liquid scintillators); Time projection Chambers (TPC)

ArXiv ePrint: 2108.01902

Lexi Bach Physics Teacher at The Steward School Richmond VA
Former Student of Mike Fetsko, Godwin High School Henrico, VA
HU-WM-GWU QuarkNet Center (Virginia Center)
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Early and High School Years	Academics
I spoke with Lexi on September 17, 2024, during a Zoom meeting. When asked a general question about what had sparked her interest in science or STEM, Lexi noted that both of her parents are engineers, and her father is a physician as well. "There was no shortage of science in my household." She said that growing up she remembers field trips to look at the bridges that they had worked on and similar things like that. She said that science was seen as a prominent value in her upbringing and that her parents cared a lot about her math and science education. Because of this, she described that she was always ahead in math and science due to the support she got from home and maybe a predisposition with all of these things mixed together. As a junior, Lexi took an Honors Physics course with Laura Akesson (another QuarkNet teacher). This was her first physics class, which she described as amazing with an incredible teacher. Lexi said that she knew she could always do math and science, and her parents instilled a hard work ethic, even if it wasn't easy if she worked hard, she could get it. In that class, Lexi said that things all came together. She understood how to do the math, understood how to apply it, understood the concepts. She indicated that that was her "ah-ha" moment. Experiencing success, she was able to help her peers, a leadership role she was not familiar with. She described this as a great opportunity; she was successful and wanted to learn more. As to her AP Physics class with Mike Fetsko in her senior year of high school, Lexi described this class as very challenging. Despite the challenges, she maintained her interest and knew that she wanted to pursue science in college. Lexi said that she felt very lucky to have had both Laura and Mike as high school teachers. When asked why she thought Laura and Mike were exceptional teachers, Lexi said that they both love physics and they love fostering the "ah ha" moments for their students no matter how big or how small – each teacher views this as a win balanced between the challenges of a hard subject and working toward a hard earned, hard fought for grade. Lexi graduated from high school in 2008.	Lexi enrolled in Brigham Young University in 2008. The university has an extension Physics Department, which Lexi described at first to be a bit overwhelming given the number of choices she could make under the umbrella of physics, such as astrophysics, physics, applied physics, physics education with. Course requirements varied within these fields. She said that she had switched majors during this time but ultimately picked physics teaching. When Lexi focused on a degree in physics teaching and when time came for her to do her student teaching placement, she told her advisor (who she described as incredibly supportive) that she wanted to do her student teaching with Mike Fetsko (back at Godwin). This out-of-state placement request was unusual but with her advisor's help she was able to accomplish this goal. Lexi noted that through observing other physics teachers she realized that Mike Fetsko was one of the best. She started her student teaching in January 2014 with Fetsko for a four-month period (through April 2014). This was a year before AP Physics I became a main stream course. Lexi described how this was a unique opportunity for her because as Mike was building this course, she got firsthand experience as to what creating a course looks like. At the time, the standards were very new and how to achieve the objectives and meet the standards were challenging. Lexi described this as an important learning experience. Lexi earned a BS in Physics Education (2014).

Lexi Bach is a high school science teacher. She taught at Godwin High School in Richmond VA for six years. Since 2022, she teaches Physics and Chemistry at The Steward School (a private, K-12 school in Richmond, VA). She is both a former student and teacher at Godwin high school and she participated in QuarkNet both as a student (2008) and as a teacher (starting in 2014).

Teaching High School Physics and Science Experience: At the time Lexi completed her student teaching placement and her undergraduate degree, Godwin High School projected an increase in physics enrollment for the next year. After formally interviewing and receiving an offer, Lexi began teaching at Godwin in 2014. She said that this offer was both a humbling and exciting experience because she knew that she had "landed at a phenomenal school with a phenomenal coworker." She felt very grateful and supported. Lexi taught Honors (11th grade) and AP Physics (12th grade) at Godwin, where she taught for six years.

In Spring 2020, as a mom of two small children at that time, Lexi took a hiatus from teaching in Spring 2020 (right before COVID). She said this was a very hard decision because "my heart and soul were at Godwin." She resumed teaching in Fall 2022 at The Steward School where she teaches first-year physics and junior year Chemistry.

QuarkNet Experience as a Student:

As a high school student, Lexi described how they did some activities around particle physics which was timely as CERN nearing completion was in the news (2008). They went on a field trip to Jefferson Lab to see their accelerator and participate in a QuarkNet masterclass. She thought this was a great opportunity to interact with these scientists before going to college. [Jefferson Lab is in Newport News, Virginia and dedicated to researching nuclear physics, materials science, and accelerator science. Home | Jefferson Lab (jlab.org)]

On reflection, Lexi indicated that in 2008 QuarkNet was a relatively new program and needed to improve as to how to engage high school students at a level where students could grasp and understand concepts. But she said to see the real modern science (interacts with scientists, the activities, gathering data from the accelerator and determining what they were looking for and why is this important) was an inspiring and interesting experience for her. This was her first exposure to real-world, authentic data.

QuarkNet Experience: As a Teacher

Lexi became an active participant (as a teacher) in QuarkNet during the 2014-2015 school year. By then, she noted, QuarkNet had improved; was much more streamlined, the connections with professors and scientists were much stronger and interactions with students were more at the high school level. QuarkNet was a more engaging program more tangible for students.

[In her response to the *QuarkNet Teacher Survey* in summer 2020, she noted that she had used the Data Activities Portfolio (DAP) activities in her classroom. Specifically, she wrote: "Calculating the Z-mass" as an example. "It's a great activity because it can be a competitive thing. It also reinforces some major math concepts." And she noted "They are (DAP activities) a great intro to particle physics research, math, etc." (During the summer of 2020, Lexi participated in a STEP UP QuarkNet workshop and noted that she had previously participated in QuarkNet's Cosmic Ray e-lab)]

QuarkNet Outreach: Both Lexi and Summer Blot participated in a presentation to Godwin physics students the year before Lexi left Godwin. Mike Fetsko arranged this presentation. Both Lexi and Summer were former classmates of Mike Fetsko (in the same physics class). Dr. Blot is a Ph.D. in astrophysics and a Staff Scientist at Deutsches Elektronen-Synchrotron, DESY, Hamburg Germany, and is part of an international group of scientists responsible for the scientific research that makes up the IceCube Collaboration. This presentation occurred prior to students participating in a QuarkNet masterclass and a field trip. The presentation gave these students a first-hand opportunity to see two professionals from the same class, from the same high school, each on a separate path in physics one as a teacher and one as a researcher – both of whom are young women.

Morgan Logsdon Choi, PhD student at University of Arizona
Former Student of Mike Fetsko, Godwin High School Richmond, VA
HU-WM-GWU QuarkNet Center (Virginia Center)
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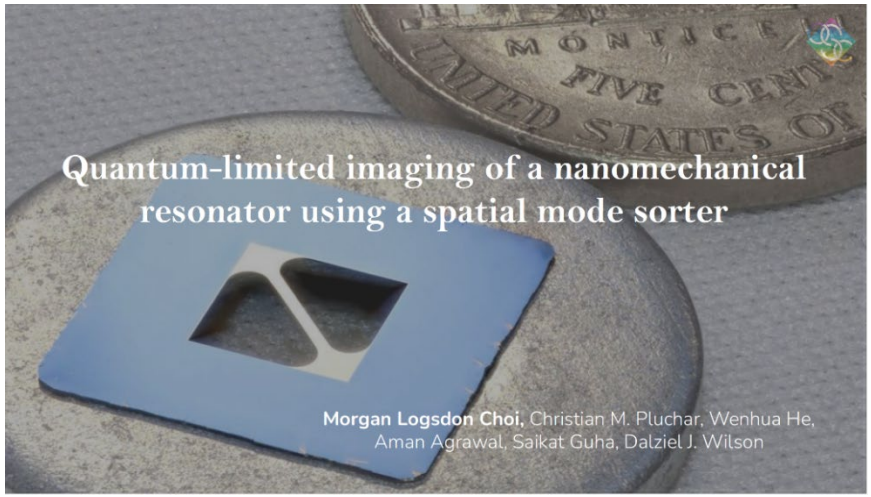
Early Years	Early Academic Accomplishments
I spoke with Morgan on September 5, 2024, during a Zoom meeting. When asked a general question about her early interest in science and math she said: *I don't think there was one particular moment in my life, but I think I can remember several times throughout my childhood, and through high school and in college where I found my love of science reaffirmed.* She said that she grew up in Turkey where the school system places a high value on the importance of math education. She found it challenging and fun. At home, she would play math games with her father (who is an engineer). When she went on road trips, as her father drove, he would have Morgan read books to him (whatever he was reading at the time). These books were often very technical, for example, the history of physics or related to physics topics of interest to him. (She was about 7-9 years old at the time and an avid reader.) Over time, Morgan said that this made science less threatening, and science did not seem intimidating because she became familiar with some of these terms and in hearing stories about individuals who became scientists. Morgan said that she always loved science and described during a brief period when she was home schooled, where her mom borrowed scientific equipment. Her mom found a microscope and pre-made slides that Morgan would spend hours looking at. She loved learning about how the world works. In high school, her AP Physics I and AP Physics II classes (junior and senior years) taught by Mr. Fetsko introduced her to different ways to think about science, beyond how to practically apply science, and think about how science can be used for wider explorations and aligned with her love for understanding how the world works. During these classes, it was her first experience using authentic data. She credits her high school physics classes, her QuarkNet engagement, and relationships with different universities in her pursuit of a degree and career in physics.	In 2017, Morgan was a recipient of the Governor's Award for Women in STEM awarded to five students statewide to high school juniors and seniors who plan to pursue STEM careers at institutions of higher education. Reception hosted by Governor Terry McAuliffe and the Virginia Council on Women. Morgan graduated from Godwin High School in 2018. It was her decision on which college to attend, that lead Morgan to decide on physics rather than obtaining a degree in engineering. Her decision came down to two schools, an engineering school and William and Mary. She indicated that the College of William and Mary has a reputation of encouraging and prompting undergraduate research. In the physics department there is a one-to-one ratio of professors to students, offering a solid foundation on fundamental physics. Her choice to pick William and Mary also confirmed her intent to pursue a Ph.D. She described how her ties to William and Mary also came during high school. Mr. Fetsko has a close relationship with Dr. Joseph Erlich, a professor at William and Mary who is also involved in QuarkNet. She and other students took field trips to William and Mary. During one of the lab tours, Morgan visited the lab of Dr. Seth Aubin; she described being very fascinated with the work he was doing. During her first year at William and Mary, Organ asked for a second tour of Dr. Aubin's lab. He then asked her to work in his lab as an Undergraduate Research Assistant, Ultracold AMO Lab from (2019-2022). She received a BS in Physics with a minor in Data Science in 2022. Her undergraduate honors thesis was titled, *Co-planar Waveguides for Microwave Atom Chips Co-planar Waveguides for Microwave Atom Chips*, (Morgan Logsdon May 2022).

Morgan Logsdon Choi is a graduate student at the University of Arizona. She is pursuing a Ph.D. in Optical Science (expected in 2028). She is the recipient of the Robert M. Edmund Graduate Student Endowed Scholarship in Optical Sciences awarded to top ranked incoming graduate students to fund first-year research (2022). Her research interests include quantum imaging, optomechanics, precision metrology, and quantum sensing. She is a Graduate Research Assistant in Dr. Dalziel Wilson's Quantum Optomechanics Lab where she performs "quantum-limited imaging of naomechanical resonators in vacuum using spatial mode demultiplexing" and analyzes "power-spectral densities to identify noise and signals in the frequency domain."

Oral Presentation



Morgan E. Choi, Christian M. Pluchar, Wenhua He *et. al*. "Quantum-limited imaging of a nanomechanical resonator using spatial demultiplexing," NMC Workshop for Nanomechanical Resonators, Main Session. Vienna, Austria. (Summer 2024).

Poster Presentations

- Morgan E. Choi, Christian M. Pluchar, *et. al*. "Active Imaging of a Nanomechanical Resonator Using Spaial Light Demultiplexing," Charting Quantum Horizons, hosted by Arizona Quantum Initiative & NOIRLab (Spring 2024).

- **Morgan E. Choi**, Christian M. Pluchar, *et. al.* "Quantum-Limited Imaging of a Nanomechanical Resonator," Graduate Student Recruitment: Research Showcase, hosted by University of Arizona (Spring 2024).

Outreach Efforts

Morgan's outreach efforts have included

8th Grade Science:
Pinhole Cameras (Upcoming 2024)
Colorblindness, Diffraction and the Electric Pickle (2023)

AP Physics I:
What are Bose-Einstein Condensates? (2020)

AP Physics I, II:
Research in "Quantum Optomechanics" (2023)
A Diversity of Physics Research Opportunities (2021)

She was a member of Women in Physics Student Organization (club for undergraduate women in physics) College of William & Mary (2019-2022) and she was a Mentee in the Women in Physics Mentorship Program mentored by a female physicist at the Army Laboratory (2022).

Source for the above*: Morgan E. Choi, Curriculum Vitae September 2024*

Anvita Korrapati Undergraduate student at University of California Berkeley
Former Student of Mike Fetsko, Godwin High School Henrico, VA
HU-WM-GWU QuarkNet Center (Virginia Center)
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Early Years	High School Influences
I spoke with Anvita on September 7, 2024, during a Zoom meeting. When asked a general question about her early interest in science, Anvita noted that when she was about five or six years old, she was very interested in hair, cutting hair and using hair products, she sprayed her sister's hair with lemon juice while washing it. The next day her sister's hair was a "whole difference shade" and she realized that the sun and lemon juice would lighten one's hair color. That sparked her interest, she thought that this process was interesting to explore. And she was "very into reading books, I love books" she took out books from the library about space, Roman mythology because of their planetary names; this along with watching movies about aliens sparked her interest in science and math; and then later her interest in technology. Anvita said that since she was in third grade she wanted to be an astronomer. As a middle schooler she participated in a program through Virginia Commonwealth University where she was able to simulate and create her own Mars Rover. And she participated in science fairs at her middle school through the International Science and Engineering Fair. (Her interest and participation in science fairs continued in high school as well.) In eighth grade Anvita learned about the Astronomy Club at Godwin High School. Anvita went to Godwin High School because of its Astronomy Club only to learn as a first-year student that it had been disbanded. As a first-year student and sophomore, she tried unsuccessfully to restart the club (Anvita's junior year was disrupted by COVID).	As a high school senior, Anvita took an AP Physics II class with Mike Fetsko. She had asked him for help in reestablishing the Astronomy Club. As an alternative, she said that he managed to recruit her as a member of the Physics Club. Up until then, she knew that physics was an integral part of astrophysics, and she had some interest in it. She said that because of Mr. Fetsko explanations of concepts such as electricity, magnetism, and fluids, she said that she was drawn to them and realized that physics and math were a great combination and helped her to realize her interest. She described that the best part of this class was the labs, very hands on and she along with her students were encouraged to go beyond to help cultivate a team setting as well as environment for learning – emulating the process of which authentic science is conducted. Anvita graduated high school in 2022. Looking back now, she discussed a project that she did in Mr. Fetsko's class. One of the main issues that Mr. Fetsko had talked about in class was climate change. She and a classmate did a project on climate impact where they used data analytics using Python to address a problem based on a comparison between companies that used reusable paper for their magazines or newspapers versus companies that did not use recycled paper. This experience left her with the impression of the importance of climate -- with earth and planet science related to astrophysics -- she realized her interest in climate and geophyiscs. She noted that Mr. Fetsko's QuarkNet experience helped him incorporate coding (such as Python) to help analyze physics data. In turn, he passed these skills to his students.

Anvita Korrapati is an undergraduate student at the University of California, Berkeley. Her major is Data Science – Physical Sciences Concentration (expected graduation 2026). She writes that she has "a solid foundation in statistical analysis, machine learning, and programming languages. Eager to apply academic knowledge to real-world scenarios and contribute to innovative data-driven solutions." (Source: Anvita Korrapati's resume)

University Academics

Anvita applied to universities based on the schools that had the best physics and astrophysics programs. She selected the University of California; Berkeley because of the Lawrence Berkeley National Laboratory (2022-2026) and she liked the potential that the Bay Area holds for future data scientists. Her original intent was a double major in astrophysics and data science.

During her first year, Anvita worked with Solene Lejosne who is an Associate Researcher at the Space Science Laboratory, UC Berkeley. Anvita worked on a project regarding geomagnetic activity near the Earth where she was able to increase her coding skills and combine this with data visualization and other data analyses. After her first physics course, she realized that her interest in astrophysics and physics stemmed from her interest in research, specifically in quantum computing related to satellite research. At Berkeley she has been able to major in data science with a concentration in physical science. She intends to work in labs, in space-related research where she wants to use her data engineering and machine learning skills, for example, to identify objects, and create algorithms. Anvita notes that her experience at UC Berkeley has helped her hone the specific nature of the research that she would like to do.

Undergraduate Research Experience

Anvita has held a Data Science Analytics and Research Internship at:

- UC Berkeley Data Science Discovery Program (September-December 2022)
- New Sun Roads (June 2023-September 2023)
- Climformatics (September 2023-December 2023)

Based on her internship experience, she has realized that what she really likes is climate research in the energy sector and using her data science in those industries. She is seeking an internship opportunity in the field of Data Analytics for Geophysics.

She is a member of the UC Berkeley Undergraduate Astronomy Society and a member of UC Berkeley Data Science Society as well as a dance teacher at the Sree Nrithya School of Kuchipudi Dance and a member of the UC Berkeley Hindu Students Association.